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CHEMICAL, MITSCHERLICH, AND NEUBAUER METHODS FOR DETERMINING AVAILABLE POTASSIUM IN RELATION TO CROP RESPONSE TO POTASH FERTILIZATION[1]

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IT IS well known that replaceable and soil solution potassium in soils do not comprise the total potassium available to plants. In many soils nonreplaceable potassium constitutes a considerable portion of the potassium used by plants (1, 2, 5, 7, 9, 11, 13, 16).[3] Hoagland and Martin (7) state that with one soil practically all the potassium was absorbed from a nonreplaceable form and this continued to be sufficient for satisfactory growth. Nonreplaceable potassium is converted into replaceable and soil solution forms by degradation of clay colloids and primary minerals occurring chiefly in the silt fraction.

To evaluate the fertility level of a soil requires a knowledge of the relative importance of replaceable and nonreplaceable potassium in that soil.

This research was concerned with establishing the relationship between crop response to potash fertilization and available potassium in important Ohio soils. Since available potassium may be derived from several sources, it is unlikely that any one method of determination will indicate consistently the amount that may be obtained from a given soil. Therefore, a combination of field, chemical, and biological (Mitscherlich and Neubauer methods) tests was employed.

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[3]Figures in parenthesis refer to "Literature Cited", p. 9.

EXPERIMENTAL

FIELD EXPERIMENTS

Six soils were selected which differ in nature of parent material, depth of leaching, texture, and probable response to potash fertilizer. The soils were Clermont, Miami, Wooster, and Muskingum silt loams, Mahoning silty clay loam, and Brookston clay. A description of these soils has been given by Conrey, *et al.* (3).

At each location 16 plots arranged in Latin square with four replications were fertilized broadcast each year at the rate of 0, 10, 20, and 40 pounds of potash per acre, and each plot received liberal applications of nitrogen and phosphate. Corn (Ohio W-17) was grown all 3 years.

Eight borings were taken at 0–7 inches from each plot before fertilization. Each set of borings was composited for each application of potash to make a total of 32 borings per 1/15 acre. These samples were used for the determination of total bases, exchange capacity, exchangeable potassium, and for the Neubauer work. Soil was collected from between the plots for the Mitscherlich study.

MITSCHERLICH EXPERIMENTS

The method used was essentially that described by Dühring (4) for the Mitscherlich pot culture technic with a few modifications, i.e., the indicator plant was corn instead of oats and nutrient additions did not include $CaCO_3$ or NaCl.

The weight of soil used varied slightly with soil type but was near 2,300 grams per pot. The weight of sand was 6,100 grams per pot. The depth of the sand-soil mixture was approximately 7 inches. Potash increments were equal to 0, 0.175, 0.350, 0.700, and 1.40 grams per pot. Nitrogen and P_2O_5 additions were constant and equal to 1.40 grams per pot. There were three replications per treatment.

LABORATORY METHODS AND EXPERIMENTS

Exchangeable potassium was replaced by leaching 10 grams of soil with 250 ml of neutral, normal CH_3COONH_4. Before leaching the soil was moistened with CH_3COONH_4 for about 12 hours to insure a more complete contact.

Potassium in the leachate was determined by a modified chloroplatinate method essentially that outlined by Yoe (17). Some modifications were necessary, which consisted mainly in the use of 80% alcohol saturated with K_2PtCl_6 instead of 95% alcohol for the washing solution.

To separate the silt fraction the soil was dispersed by standing in dilute $Na_2C_2O_4$ solution a day or two followed by agitation by a mechanical stirrer, washed through a 300-mesh screen to remove sand, and washed repeatedly to remove clay. Separations within the silt fraction were made by the gravity sedimentation technic.

Each silt fraction was leached with normal $CaCl_2$ and then leached free of chloride ion.

The Neubauer method (14) was used to determine the amount of nonexchangeable potassium which might be released to plants from the silt fraction and also the available potassium in the whole soil. Fifty grams of each silt fraction were used instead of the usual 100 grams for soil. According to Schachtschabel (12), such a procedure is valid when the Neubauer value is low, and the result for 50 grams of soil is very nearly one-half the result for 100 grams.

RESULTS

FIELD TEST

Yields per acre in corn and stover are shown in Table 1. Analysis of variance showed a significant difference in corn yields between

TABLE 1.—*Yields of corn and stover in relation to potash fertilizer.**

Treatment, lbs. K_2O per acre	Increase in yield over check					
	1939		1940		1941	
	Corn, bu.	Stover, lbs.	Corn, bu.	Stover, lbs.	Corn, bu.	Stover, lbs.
	Clermont Silt Loam					
10	9.2	546	6.8	278	12.1	230
20	18.4	746	16.0	648	20.3	610
40	24.4	1,096	17.5	808	26.7	1,150
Check yields	33.1	1,254	24.0	1,032	34.1	1,320
	Miami Silt Loam					
10	2.8	280	6.4	448	7.4	−60
20	13.3	270	7.7	540	10.0	40
40	8.8	850	8.5	718	13.7	390
Check yields	83.7	2,750	37.6	1,422	72.3	2,310
	Wooster Silt Loam					
10	3.3	30	4.0	495	2.7	60
20	14.0	−90	−2.3	170	2.6	[illegible]
40	19.4	160	2.8	570	−3.5	[illegible]
Check yields	45.6	2,230	86.7	2,320	49.9	1,650
	Mahoning Silty Clay					
10	2.0	430	Crop failure	—	−2.2	−360
20	5.0	620		—	4.9	0
40	11.4	420		—	7.4	−120
Check yields	66.6	1,720		—	75.2	2,520
	Muskingum Silt Loam					
10	−3.9	−60	1.5	235	−4.6	60
20	0.0	−100	3.1	190	−5.1	180
40	−0.8	140	0.4	420	−6.6	−120
Check yields	81.0	2,760	54.3	2,220	59.6	2,580
	Brookston Clay					
10	−4.6	660	3.6	140	2.7	−90
20	−0.2	800	1.1	−40	−0.8	−50
40	3.7	60	−1.4	70	0.6	−210
Check yields	65.4	2,720	59.1	2,650	56.5	2,160

*Grain yields calculated on the basis of 15.5% moisture; stover samples dried at 65° C.

treatments on the Clermont, Miami, Wooster, and Mahoning soils for 1939, but only on the Clermont and Miami for 1940 and 1941. The number of bushels between treatments necessary to be significant at the 5% level were for Clermont soil, 15.5 in 1939, 7.9 in 1940, and 14.4 in 1941; for Miami soil, 9.1 in 1939, 6.3 in 1940, and 7.7 in 1941; for Wooster soil, 6.6 in 1939; and for Mahoning soil, 9.6 in 1939 and 7.8 in 1941. In general, the stover yields increased as the corn yields increased on the Clermont and Miami soils.

MITSCHERLICH TEST

The data from the Mitscherlich experiment are summarized in Table 2. From the yield data, the root-available potash or b value was calculated from the equation,

$$b = \frac{\log A - \log (A - y)}{c},$$

where A equals maximum yield with largest addition of fertilizer expressed as 100%; y equals yield with no fertilizer added, expressed as percentage of the maximum yield A; and c equals a constant, or growth factor. In this work c was assumed to be constant and equal to 0.33 expressed in units of dz/ha (4). One dz/ha = 93.6 pounds per acre. Since 1 part of soil was diluted with 2 parts of sand

TABLE 2.—*Yields of corn stover in percentage of maximum in Mitscherlich pot tests with b values and supplementary chemical data.**

Treatment, grams K_2O added per pot	Soil type					
	Clermont silt loam	Miami silt loam	Wooster silt loam	Mahoning silty clay loam	Muskingum silt loam	Brookston clay
0	28.6	32.7	42.1	46.2	56.6	83.9
0.175	30.4	28.6	42.1	30.8	61.5	77.5
0.350	78.5	65.3	79.0	63.5	93.5	90.4
0.700	85.7	91.8	97.5	94.2	95.0	96.8
1.400	100	100	100	100	100	100
Av. yield of maximum pots in grams......	56	49	38	52	60	62
b value in lbs./acre of K_2O..............	125	147	202	230	310	675
Exchangeable K_2O in lbs./acre..........	178	188	270	314	321	670
Exchange capacity, M.E. per 100 grams	8.80	9.00	7.50	13.1	10.8	30.1
Total bases, M.E. per 100 grams.........	8.13	6.87	2.88	10.9	8.19	31.9

*All chemical data represent the average of duplicate determinations on each of the quadruplicate field plots.

by volume, the b value for the above equation was thus multiplied by 3. In Table 2 the b value represents available potash in pounds per acre in the surface layer of soil.

The value of c may be calculated from each increment of fertilizer (4). To get an indication, at least, of the correctness of the constant given by Mitscherlich, the value of c was calculated for the third increment of fertilizer (0.700 gram K_2O per pot). This increment was chosen because the first increment gave decreases with three soils and the second increment showed greater variations than the third among replications. The average c value for all six soils was 0.34 dz/ha. The variation from this average was from 0.26 to 0.49 dz/ha. It may be of interest to point out here that the lowest values for c were obtained on the soils (Brookston and Clermont) which had the highest percentage saturation of the exchange capacity with bases, while the highest value for c was obtained on the soil (Wooster) with the lowest percentage saturation. In connection with this, attention is called to the variations in the maximum yields on the soils. It was found that this maximum yield was related to the percentage saturation of the exchange complex with bases, i.e., the yields increased as a straight line function of the increase in percentage saturation, except for the Muskingum soil.

It appears from the results obtained that if $CaCO_3$ had been added some of the variations found in the maximum yields and in the c values might have been eliminated. In soils which are highly acid, such as the Wooster in this study, it seems likely that addition of $CaCO_3$ would give a more accurate check of nutrient conditions. Calcium deficiency symptoms were noticed on the plants in Wooster soil which gave the maximum yield.

When the Mitscherlich experiments were started the reason for adding NaCl with the other nutrients was not clear; thus, none was added. Further study revealed that the effect of NaCl was largely on the value of c. In the presence of sodium, c = 0.93 dz/ha; in the absence of sodium, c = 0.33 dz/ha (4).

NEUBAUER EXPERIMENTS

The results of the Neubauer tests are given in Table 3 along with the b value from the Mitscherlich method and replaceable potas-

TABLE 3.—*Comparison of chemical, Mitscherlich, and Neubauer methods for determining available potassium, expressed in mg K per 100 grams soil*

Soil	Exchangeable K (leached with N-NH_4Ac)	b value of Mitscherlich method*	Neubauer method
Clermont	7.4	5.2	2.1
Miami	7.8	6.1	4.2
Wooster	11.2	8.4	8.2
Mahoning	13.0	9.6	10.5
Muskingum	13.3	12.9	9.8
Brookston	27.8	27.8	24.6

*The b value for the Mitscherlich method represents available potassium in surface soil, or 0–7 inches.

sium. The Neubauer values increased in the same order as the values from the other two methods, except for the Muskingum soil. It was noted on this soil that the rye seedlings appeared to wilt slightly next to the sand surface and to turn a light brown or rust color, which possibly affected the absorption of potassium.

Results of Neubauer tests on silt fractions are shown in Tables 4 and 5. Comparing the total amounts of potassium removed from the entire silt fraction to that of the whole soil gives a distorted picture of true conditions. In Table 5 the Neubauer values for silt, calculated on the basis of percentages of silt found in each soil, are given, but these values are correct only in so far as the assumption is justified that the rye seedlings would absorb potassium from the unseparated silt in the soil in the same degree as they did from the silt separated from the soil.

TABLE 4.—*Results of Neubauer tests for potassium in total soil and silt fractions.*

Soil type	Total soil, mg K per 100 grams	Silt fractions, mg K per 50 grams		
		2–10 μ	10–20 μ	20–50 μ
Clermont	2.1	3.6	2.4	1.5
Wooster	8.2	5.8	3.0	2.3
Brookston	24.6	19.0	11.5	6.5

TABLE 5.—*Contribution of silt to the Neubauer potassium value of soil calculated from percentage of silt in soil and data in Table 4.*

Soil fractions	Soil type					
	Clermont		Wooster		Brookston	
	Per cent of total soil	Mg K per 100 grams soil	Per cent of total soil	Mg K per 100 grams soil	Per cent of total soil	Mg K per 100 grams soil
2–10 μ	15.8	1.1	20.3	2.4	23.0	8.7
10–20 μ	26.4	1.3	21.1	1.3	10.5	2.4
20–50 μ	28.1	0.8	34.6	1.6	11.7	1.5
Total	70.3	3.2	76.0	5.3	45.2	12.6

DISCUSSION

A final proof of a chemical or biological method intended to reflect available potassium in a soil is the response of a crop grown under field conditions to applications of potash fertilizer. Field experiments give no information on the reserves of available potassium, unless a crop response is shown. On the other hand, a chemical or biological test which indicates correctly the available potassium in a soil known to give field response, should be able to designate reserves of available potassium.

Some indication of the nature of the reserves of potassium in three of the six soils was obtained in the Neubauer studies on the silt fractions. The Clermont, Wooster, and Brookston soils were chosen because they represented marked, slight, and no response, respectively, to potash additions in the field. The results show clearly that rye seedlings were able to absorb significant amounts of potassium from the silt, which was leached free of exchangeable potassium. The amount of potassium absorbed increased as the particle size decreased. The marked differences in the amounts of potassium absorbed from these soils are most likely due to the kind and amount of potash minerals present. The Neubauer tests indicate that the potassium in mineral forms in the silt fractions of these soils can be utilized by crops during their growing period.

Some investigations on silt fractions of Russian soils (10) revealed that insignificant quantities of potassium were removed by plants. Even the clay fraction did not yield appreciable quantities of potassium to plants from nonreplaceable forms, but upon electrodialysis potassium was released in considerable amounts. Evidently nonreplaceable potassium in these soils was very slowly available to plants.

The results obtained in the present study appear to be in contradiction to those found by Maslova, *et al.* (10). However, the results of the latter were likely distorted due to the presence of sodium, a condition indicated by the fact that in three out of four cases negative values were obtained for absorption of potassium from sodium-saturated clay or soil. Since calcium-saturated systems were used in the present experiment, the results are not strictly comparable.

The results from field experiments in this study showed that two soils, the Clermont and Miami, gave a definite response to potash fertilizer over a 3-year period. Two soils, the Wooster and Mahoning, gave a slight response, and the last two soils, the Muskingum and Brookston, gave no indication of response. Thus, a range from very marked response on the Clermont to none on the Brookston was covered. This offers an excellent set of conditions whereby the relative merits of chemical and biological methods for determining available potassium can be decided.

Each method showed that the Clermont contained the lowest amount of available potassium and the Miami next lowest. The difference was very slight in the case of exchangeable potassium. The Mitscherlich and Neubauer methods showed greater differences, which corresponded more nearly with field response. Neubauer values were less than the exchangeable potassium on every soil and the same was true for the b values, except on the Brookston soil where they coincided. The Neubauer method indicates very well the available potassium as shown by field response for the soils in this study. On those soils showing no field response, the Neubauer values agreed fairly well with available potassium by the Mitscherlich method and with exchangeable potassium.

No general agreement has been found to exist between exchangeable potassium by leaching and the Neubauer values. Gisiger (6) concluded that NH_4Cl-exchangeable potassium in acid or potash-rich

alkaline soils exceeds the amount of potassium rye seedlings can absorb in a single growth period, but in alkaline soils deficient in potash the seedlings may obtain twice as much potassium as that determined by leaching with NH_4Cl.

In California soils (8) the Neubauer method frequently gave much higher values than the method of base replacement, but sometimes the reverse relation was true. However, the Neubauer method gave a much more consistent index of potassium availability than the method of base replacement when values for potassium by the latter method were low. This agrees very well with the results obtained in the present study.

Thornton (15) found that the chemical test for replaceable potassium gave a lower value than the Neubauer method. The reverse relationship was found in this study; however, the chemical tests were not conducted in the same manner, since Thornton employed a rapid chemical test with a short period of extraction.

Perhaps the explanation for the differences between chemical tests and Neubauer values is to be found in the effect of pH of the soil on each method. According to Thornton (15), with chemical tests the available potassium showed a tendency to decrease with increasing pH. In contrast, the Neubauer method showed slight correlation between pH and available potassium. Gisiger (6) states that the Neubauer method appears to be independent of soil pH, at least between the range 5.5 to 8.1.

According to Mitscherlich (4), a soil in general should be fertilized if it contains less than about 175 pounds of available potash in the surface layer. This would mean that in the present study the Clermont and Miami were deficient in available potassium which corresponds again to field response.

It may be concluded from this comparison of chemical and biological methods to field response that each indicated a low supply of available potassium in soils on which crops were most responsive to potash fertilizer. As field response decreased, available potassium increased. The Mitscherlich and Neubauer methods gave a better differentiation of available potassium than the chemical test on the two soils which gave the most response in the field.

SUMMARY

A study was made of the crop response to potash on six Ohio soils from 1939 to 1941. Corn was grown each year. A definite crop response was shown each year on the Clermont and Miami soils, a slight crop response was found on the Wooster and Mahoning soils, and none on the Muskingum and Brookston soils.

The available potassium in each soil was determined by chemical, Mitscherlich, and Neubauer methods. All methods agreed in placing the soils in the same order with respect to available potassium as indicated by field response. The Mitscherlich and Neubauer methods gave a somewhat better differentiation of available potassium than the chemical test in the two soils which showed the most crop response to potash additions.

The Neubauer method was used to study the amount of non-exchangeable potassium released from the silt fractions. Only three soils, the Clermont, Wooster, and Brookston, were examined. Significant amounts of potassium were removed by the rye seedlings from each fraction. As the particle size decreased, the amount of potassium removed increased. The lower the exchangeable potassium in the soil the greater was the proportion of potassium taken up from the silt fraction.

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EFFECTS OF PASTURE PRACTICES ON ROOT DISTRIBUTION[1]

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IN CARRYING out pasture management studies for soil erosion control, an apparent increase in roots near the soil surface that seemed to be related to the practices involved was observed. The character of changes in root growth and distribution in the soil horizon may affect plant survival, compatability of species in mixtures, response to surface fertility treatments, soil moisture relationships, and erodibility of the soil. It seemed desirable, therefore, to ascertain whether the apparent differences were real; and, if so, to attempt identification of their causes.

Measurements of root growth in turf studies have shown effects of varying degrees of clipping and interaction effects of closeness of clipping and fertility treatments. In general, the results of these studies (1, 2, 3, 4, 7)[3] show reductions in root growth when continued severe clipping is practiced. Where there was no interaction between fertility treatment and closeness of clipping, the reductions measured appeared to be a result of reduced metabolism caused by continued removal of the synthesizing members of the plant. In the interest of brevity, the term "root density" will be used in this paper to designate quantity of roots per unit volume of soil.

Measurements have also shown marked reductions on root density of turf grasses due to interactions of severe foliage denudation and nitrogen applications (2, 3, 4). This interaction is generally explained upon the basis of an unbalanced nitrogen metabolism. Unlike "luxury" consumption of potash and phosphate, an excess of available nitrogen appears to affect the nature of the end-products of photosynthesis. In this interpretation, carbohydrates are utilized principally in protein synthesis until excess amino acids are exhausted. Due to severe reduction of the photosynthetic area, the plant is unable to synthesize carbohydrates in excess of those used in the nitrogen metabolism; and, hence, carbohydrates for storage and root tissues are sharply limited. The products of photosynthesis are thus utilized principally in parenchymatous tissues, such as leaves, rather than in the relatively woody root tissues. When the plant has photosynthetic area sufficient for carbohydrate synthesis in amounts above those utilized in nitrogen metabolism, nitrogen fertilizer applications result in an increase of root growth (1, 2, 7).

Fertility treatment may also directly affect the character of root growth by chemotropism. Like many other tropisms, the physiology of chemotropism of roots is not clearly understood. However, it is known that positive and negative reactions of roots occur in response to certain salts within limited concentrations of the salts (6). Positive responses are commonly expressed by branching and development of

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[3]Figures in parenthesis refer to "Literature Cited", p. 18.

secondary roots in the region of favorable concentrations of the stimulating salts.

It has not been clearly established whether normal continuous grazing practices on unfertilized pastures of the humid northeastern states are sufficiently severe to effect a serious reduction in root density by sustained leaf removal. Neither has it been established whether rotational grazing is necessary to avoid unbalanced nitrogen metabolism on heavily fertilized pastures of the humid region.

Available experimental results do not permit a clear distinction between fertilizer effects upon root growth ascribable to chemotropic response and those due to nitrogen metabolism under normal grazing practices. In pasture practice, corrective measures for limitations of carbohydrate synthesis within the plant are largely concerned with grazing management, while corrective measures for limiting factors within the soil are accomplished largely by fertility treatment and soil management. It would, therefore, appear important from the standpoint of pasture practices to determine which of these factors plays the leading role under field conditions.

Samples for the study were collected from a series (5) of management practices with bluegrass pasture located on Dutchess loam near Sussex, N. J. The soil of the experimental site is inherently fertile but somewhat stony. Practices represented in the layout were rotational grazing with fertilizer (series A), continuous grazing without fertilizer (series B), continuous grazing with fertilizer (series C), and rotational grazing without fertilizer (series D). Treatment and management histories of the respective series are shown in Table 1.

TABLE 1.—*Treatment and management history of experimental pasture series.*

Year	Field series	Fertility treatment				Grazing management
		N*	P_2O_5*	K_2O*	Lime†	
1937	A, B, C, D	None	None	None	None	New seeding; not grazed
1938	A, C	48‡	120	50	1.5	Rotational
	B, D	None	None	None	None	Continuous
1939	A, C	48‡	None	None	1.5	Rotational
	B, D	None	None	None	None	Continuous
1940	A, C	49‡	50	50	None	Rotational
	B, D	None	None	None	None	Continuous
1941	A	54‡	60	125	None	Rotational
	C	54‡	60	125	None	Continuous
	B	None	None	None	None	Continuous
	D	None	None	None	None	Rotational

*Pounds per acre.
†Tons per acre.
‡Nitrogen was split into April and June applications.

Dairy heifers were used for grazing on all pasture series. Animal load on the continuously grazed series was maintained to keep the

forage at approximately 1 inch height, but overgrazing was avoided. In this respect, the continuously grazed series of this study are more or less comparable to the "controlled" grazing practices of some areas. Measurements from the present continuously grazed series are not comparable to results from overgrazing practices in which severe defoliation is permitted and where animal body weight is scarcely maintained.

Grass on the rotational series was allowed to reach a height of 3½ to 4 inches before the start of each grazing period. Animals were removed when the forage was reduced to 1 inch in height. A sufficient animal load was carried to effect this reduction within approximately 10 days of grazing.

All fertility treatments were made as surface applications, no treatment being made at the time of seeding. Sulfate of ammonia was used as the nitrogen carrier in the April applications and nitrate of soda was used in June applications. The phosphate carrier was 20% superphosphate in 1938 and 1940 and 30% superphosphate in 1941. Fifty per cent muriate was used as the carrier of potash.

Samples for root measurement and chemical tests were collected during the last week of August 1941. Stand counts made at the time of sampling showed a species composition of approximately 50% Kentucky bluegrass, 15% redtop, 15% timothy, 10% white clover, and 10% weeds, with no significant variations between series in plant population. Rainfall during 1941 was below normal during March and April; however, monthly precipitation from May through August was approximately normal. Yield during the 1941 grazing season was 260 thousand-pound-cow-days per acre on the fertilized series and 150 thousand-pound-cow-days per acre on the unfertilized series.

METHODS

Six sample locations were taken at random on each of the four pasture practices considered. Samples for root measurements consisted of a 6 by 6 inch soil column taken intact from each of the sample locations. The columns were taken to the laboratory, dressed to exact horizontal dimensions, and separated into horizons of 0–1, 1–2, 2–4, and 4–6 inches, respectively, with reference to the soil surface. The 0–1 inch horizon included all underground members below the point of leaf origin. Hence, the upper fraction included underground stolons but did not include surface stolons, the latter being separated at the point of root origin. Upon separation, each fraction of the soil column was washed, the roots dried at 85° C, and weighed.

Soil samples for chemical tests were taken at each sample location at depths of ¼ to 2 inches and 4 to 6 inches, respectively. The soil samples were taken from the sides of the holes left by the extracted soil columns and their identity with respect to the root samples maintained throughout. Quick tests for available phosphate and potash and colorimetric pH determinations were made on each soil sample, using methods described by Thornton, *et al.* (8).

RESULTS

Relative amounts of available nutrients as determined by quick tests are shown in Table 2 for soil samples taken on the experimental

site before initiation of treatment variables and at the time of collection of root samples. In Table 2 and subsequent tables listing relative amounts of available nutrients, the numerical values entered are those assigned by Thornton, *et al.* (8), to their test charts that represent for phosphate tests "pounds of P_2O_5 per acre, 6-inch depth, soluble in pH 1.0 reagent" and for potash tests "pounds of exchangeable K_2O per acre, 6-inch depth." Since the depths of soil samples taken for these observations are not from 6-inch depths, the values should be regarded as relative concentrations rather than pounds per acre.

TABLE 2.—*Summary of nutrient tests of composite soil samples from the 0–8 inch horizon.*

Year	Field series	Relative amounts of available nutrients		pH
		Phosphate	Potash	
1937	A, B, C, D	42	173	5.8
1941	A, C	77	100	6.6
	B, D	37	40	5.7

The oven-dry weights of all root samples were computed to a common basis of grams per 1,000 cubic inches of soil. The average weight of the six replicate root samples under each of the four pasture practices is shown in Table 3. Analysis of root sample data for variance introduced by management, treatment, and interaction of management and treatment, respectively, is listed in Table 4. Significant differences in root distribution due to treatment were found at the 0–1 and 2–4 inch horizons, respectively. The 19 degrees of freedom in the 2–4 inch column in Table 4 is caused by the loss of one sample from this horizon. Yates' method (9) of statistical treatment for incomplete records was used in analyses involving the missing value.

TABLE 3.—*Grams of oven-dry roots per 1,000 cubic inches of soil at four horizons under two management practices and two treatment practices.*

Soil horizon, inches	Rotationally grazed		Continuously grazed	
	Fertilized (Series A)	Unfertilized (Series D)	Fertilized (Series C)	Unfertilized (Series B)
0–1	264.5	228.5	299.8	213.2
1–2	38.8	44.7	40.8	33.7
2–4	12.2	16.3	11.7	13.7
4–6	8.3	10.7	7.0	9.0

Mean weights of root samples grouped according to fertility treatment and according to management practices, respectively, are given in Table 5. Each value in the body of the table is a mean of 12 measurements, the management variable being ignored in determining the treatment variable, and *vice versa*. It will be noted that the

TABLE 4.—*Analysis of variance for root distribution in four soil horizons under different pasture practices.*

Source of variation	Degree of freedom	Variance in soil horizons			
		0–1 in.	1–2 in.	2–4 in.	4–6 in
Management........	1	600.0	122.0	15.0	13.0
Treatment..........	1	22,571.0*	3.0	42.0*	28.0
Interaction:					
Mgm × treatment	1	3,850.0	253.0	22.0	0
Error..............	20	3,006.0	207.0	8.3†	7.5

*Significant.
†Error has 19 degrees of freedom.

differences ascribable to treatment show a significantly higher concentration of roots in the 0–1 inch soil horizon under the fertilized practice but a significantly lower concentration of roots in the 2–4 inch horizon for the fertilized practice.

TABLE 5.—*Means of root samples from four horizons summarized by treatment and management group, respectively.*

Soil horizon, inches	Grams of dry roots per 1,000 cu. in.				Differences necessary for significance
	Treatment		Management		
	Mean of all fertilized	Mean of all unfertilized	Mean of all rotationally grazed	Mean of all continuously grazed	
0–1	282.2*	220.8	246.5	256.5	46.7
1–2	39.8	39.2	41.8	37.3	12.3
2–4	11.9	15.0*	14.3	12.7	2.5
4–6	7.7	9.8	9.5	8.0	2.3

*Differences significant.

Mean values of chemical tests on soil samples from the ¼–2 and 4–6 inch horizons, grouped according to treatment practices, are listed in Table 6. Each value in the table is a mean of 12 determinations.

TABLE 6.—*Mean values of chemical tests on soil samples taken at two horizons under two treatment practices.*

Soil horizon, inches	Relative amounts of available nutrients				pH	
	Phosphate		Potash			
	Treated	Untreated	Treated	Untreated	Treated	Untreated
¼–2	142.0	31.0	322.0	78.0	6.5	5.3
4–6	60.0	29.0	27.0	39.0	6.1	5.3

For purposes of correlation of root distribution and soil tests, the sum of root samples from the 0–1 and 1–2 inch horizons were associated with soil samples from the ¼–2 inch horizon. The unit of separation of soil samples and root samples was identical in the 4–6 inch horizon. Correlations of root distribution and nutrient tests, together with correlation of nutrient tests with each other, are listed as correlation coefficients in Table 7 for two soil horizons under fertilized and unfertilized treatments, respectively. Each of the correlations was calculated from 12 pairs of readings.

TABLE 7.—*Correlation of chemical tests and root distribution in two soil horizons.*

Depth, inches		Fertility treatment group	Correlation coefficient, 4*					
Soil samples	Root samples		Roots × phosphate	Roots × potash	Roots × pH	Phosphate × potash	Phosphate × pH	Potash × pH
¼–2	0–2	Untreated	+0.7566†	+0.4345	−0.4213	+0.2576	−0.1842	−0.3012
¼–2	0–2	Treated	+0.3453	+0.3029	−0.2639	+0.4271	+0.4829	+0.2751
4–6	4–6	Untreated	−0.1729	+0.8178†	−0.2251	+0.0506	−0.3158	−0.1144
4–6	4–6	Treated	+0.0275	+0.6459*	−0.5984*	−0.2574	−0.8461†	−0.4897

*For 5% P, r = 0.5713.
†For 1% P, r = 0.7008.

DISCUSSION

Possible differences effected by grazing managements employed in this study were less than those effected by fertility practices, since the former fall within the range of precision that obtained. The relatively small range of differences effected by grazing management, as compared with effects of fertility treatment, would not be expected where variables of grazing management included differential closeness of grazing throughout the spring period of root formation or where severe overgrazing was practiced through the grazing season. Sharp reductions in root density have been reported (1) as a result of continued severe defoliation of sod grasses.

In Table 5, a significant difference in root density in favor of ferterlity treatment is found in the surface horizon. The 1–2 inch horizon appears to be a zone of equality with respect to effects of fertility treatment upon root density. Below 2 inches depth, higher root densities are found under unfertilized than under fertilized sod. Although differences in the 4–6 inch horizon are not statistically significant, the small volume of roots involved affects the precision of measurement. Increased experimental precision would probably prove the validity of these differences.

Based upon the assumption of carbohydrate-synthesizing capacity within the plant as the controlling factor in maintaining a favorable nitrogen-carbohydrate ratio, the higher root density of the present fertilized series, given in Table 5, would indicate that reduction of photosynthetic area by grazing was not sufficiently severe to reduce carbohydrate synthesis below the amount needed by available

nitrogen for protein synthesis. Since the upper horizon in these managements includes the majority of storage organs of the plant, the increased weight would indicate that storage took place within the plant.

The explanation of the lower root density found at the lower horizons of the fertilized sod is less direct since the assumption of a nitrogen-carbohydrate ratio that permits storage of carbohydrate reserves would indicate that these materials would also be available for woody tissues of roots and hence would be reflected in a general increase of these members. Interpreted on the basis of the effect of nitrogen metabolism, it would be necessary to assume that the narrow nitrogen-carbohydrate ratio that prevails during spring growth limited availability of materials for root growth during the spring period and that the differences measured would be the residual effect of that condition. The storage as reflected in increased weights in the upper soil horizon would, of course, have formed during the summer growing season subsequent to the period of active root increases.

Analysis of the data in Table 4 does not support this interpretation since the occurrence of this condition would be expected to be expressed in a significant interaction of management and treatment in the lower horizons. In field practice, the number of animals stocked by the ordinary dairy farm is not large enough to consume all available pasturage during the spring growing season. Accordingly, where very early grazing is avoided, over-grazing during the spring period of root formation is uncommon.

The above interpretations indicate that, at least during the summer growing season, root formation was not retarded by an unfavorable nitrogen-carbohydrate ratio within the plant under the grazing and fertilizer practices studied. Attention is accordingly directed toward the plant medium as the source of the measured differences in root density. Since phosphate, potash, and pH are the only factors of plant medium measured in the present study, examination of plant medium inter-relationships are confined to these factors.

It will be noted in Table 6 that available phosphate and potash on the treated series is relatively high in the surface horizon so that these would not be expected to be limiting factors if root development were dependent upon these nutrients. In Table 7, a positive but nonsignificant correlation is found between roots and each of these nutrients for this horizon and treatment. In the upper horizon of the untreated series, potash is low and phosphate is very low. Both are positively correlated with root density, the correlation with phosphate being highly significant. In the lower horizon, potash and phosphate are very low on both series. Significant correlations of root density with potash are found under both series and no correlation is found with phosphate on either series at the lower horizon. Based upon these correlations, potash would be indicated as a limiting factor to root development where this nutrient is low. Chemotropism of the roots would presumably account for the increased root density in the vicinity of potash concentrations. The significant correlation of roots and phosphate in the upper

horizon of the untreated series is not clear in view of the nonsignificant correlation of this nutrient in the lower horizon of both series. The precision of the phosphate test is relatively uncertain in the range of low concentration and may account for the inconsistency. *A more likely explanation is that unmeasured differential chemical* relationships between the two horizons affected the factors concerned or the precision of their measurement.

A negative correlation of roots and pH, or expressed differently, the positive correlation of roots and acidity, similar to those shown in Table 7 was noted by Sprague (7) who suggested that conditions under low pH were unfavorable for agencies of decomposition and that measurement probably included presence of dead roots. Although quantitative measurements of dead and live roots is difficult, this interpretation should be verified by further measurements.

Obviously, the factors measured in Table 7 do not represent a complete list of factors in the plant medium that could have directly or indirectly influenced root development under conditions of the experiment. It is equally obvious that the positive correlations found could be the result of intercorrelations of unmeasured factors that would affect either the quantity of the factors measured or the methods employed in their measurement. The existence of these correlations, however, emphasizes the possibility that limiting factors of the plant medium may take precedence over the physical capacity of the plant for synthesis under conditions of nitrogen stimulation and that at least a part of these factors may be subject to control under field conditions.

The net effect of fertility treatment in reduction of root density at the deeper soil horizon would be expected to affect drought resistance and winter survival of the grass species concerned. Observations in the field have indicated a condition contrary to this expectation.

The property of resistance to erosion, commonly exhibited by good stands of grass, is undoubtedly due in part to concentration of roots near the soil surface. It appears that surface fertilizer applications on pastures should contribute to the conservation of soil and water through both the increase in density and vigor of aboveground plant parts and the increased concentration of roots in the upper soil layers.

Since practically all fertility treatments on permanent pastures are surface applications, it would seem that the increase of roots near the surface, while a consequence of the fertility treatment itself, would increase the effectiveness of those treatments which have rather shallow penetration. It would also appear that consideration of the character of root response to surface applications should be considered in selecting pasture species for intensive fertility treatments. Generally it is not possible to control the mineral balance of soil by surface applications to a depth greater than 1 or 2 inches and the plants selected for fertilized permanent pasture should have feeder roots within this zone.

Where a mixed stand of grasses and clovers is desired, the factor of nutrient balance would appear to be a more difficult and acute problem than when dealing with a single species. Since such a mixed

species is generally desired by dairymen for pastures, the present trend toward increased use of fertilizers on pastures emphasizes the need for evaluation of the effect of nutrient balance upon metabolism and survival of specific plants and of mixed stands under field conditions.

SUMMARY

A study of root growth of pastures as affected by management and treatment practices is reported.

An increase of roots near the surface and decrease of roots below 2 inches was associated with surface fertility application.

Positive correlations were found between potash and root growth at low potash concentrations and between root growth and phosphate at high phosphate concentrations.

As evidenced by effect upon root growth, continuous moderate grazing of nitrogen-fertilized pastures did not prevent carbohydrate storage during the summer grazing season under conditions of the study.

The significance of an increase in root concentration near the soil surface in relation to the control of erosion is noted.

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THE GERMINATION AND EARLY SEEDLING DEVELOPMENT OF TWELVE RANGE GRASSES[1]

A. PERRY PLUMMER[2]

GERMINATION and early stages in seedling development are critical periods in the life of range grasses. Once a plant that is adapted to a site has lived through the seedling stage, it may be expected to endure the fluctuations of that environment. The natural assumption in testing species for range reseeding under various environmental conditions is that those species which are native to the desert and are successfully meeting the vicissitudes of a xeric climate would tend to germinate and establish themselves quicker than more mesophytic species. Adaptability trials made from the most desert sites to the more mesic habitats in the Intermountain region have shown, however, that some of the most xerophytic species are often the most difficult to get started, while species native to mesic sites may often produce good stands on drier sites although they may later succumb to drought.

In order to understand more fully the relationship between early development and the successful establishment of reseeded stands, some aspects of germination, emergence, and especially the early development of 12 grass species from various habitats were investigated.

Literature on germination and response to depth of planting of seeds is fairly abundant (4, 5, 6, 7, 9, 12, 15).[3] For most grasses alternating temperatures of 20° C for 18 hours and 30° C for 6 hours are generally recommended. Specific literature regarding depth of planting of grasses used in range reseeding is more limited. However, most workers are agreed that *Agropyron cristatum* (L) Gaertn, *A. trachycaulum*[4] (Link) Malte *Bromus inermis* Leyss, and other species with seed of similar size show maximum emergence when planted between ½ and 1 inch deep, although shallower plantings may produce equally good results under optimum moisture conditions.

Very little has been published on the development of young perennial grass plants. Growth of roots in successive stages of development has been especially neglected. A number of studies of root development of corn, sorghums, wheat, rye, oats, and grasses of the Great Plains have indicated that the development of the root system is of fundamental importance, and marked differences in root development between species and varieties occur (2, 3, 8, 13, 14, 16, 17, 18, 19).

Pavlychenko (10) made careful detailed quantitative studies of the entire root system of several weed and crop species under field conditions in Canada. He found (11) that 3-year-old single plants of *Agropyron trachycaulum*, *Bromus inermis*, and *A. cristatum* had produced 9.9, 65.2, and 315.4 miles of roots, respectively.

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[1]Contribution from the Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah. Received for publication July 27, 1942.

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[3]Figures in parenthesis refer to "Literature Cited", p. 34.

[4]The International Code of Nomenclature recently adopted by The Bureau of Plant Industry is followed in this paper. *Agropyron trachycaulum* has been widely known as *A. pauciflorum*.

Bailey (1) compared the root systems of three western grasses (*A. smithi* Rybd., *B. carinatus* Hook & Arn., and *A. ciliare* (Trin.) Franch.) at the end of the first growing season and found considerable difference in the extent of roots.

Love and Hanson (7) made comparisons of the root and shoot systems of *A. cristatum* and *B. inermis* 10, 17, 24, 31, and 45 days after planting in the greenhouse. During the first 24 days *B. inermis* had a distinct advantage, after which *A. cristatum* developed just as rapidly and considerably faster toward the close of the study. This was suggested as one explanation of the ability of *A. cristatum* to establish itself more successfully on dry sites.

EXPERIMENTAL PLANT MATERIAL

The 12 species used in this study are representative of a wide and diversified range of habitats. On the basis of numerous experimental plantings in the Intermountain region these species are briefly described as follows:

Agropyron cristatum has yielded the most consistently good results in the lower foothills and semidesert areas. *Agropyron spicatum* (Pursh) Scribn. and Smith has developed good stands on the same sites but has not been as consistently successful. *A. trachycaulum*, *Arrhenatherum elatius* (L.) Mert. and Koch., *Bromus carinatus*, *B. inermis*, and *Elymus glaucus* Buckl. are more aggressive and better adapted than the former to the higher elevation of the mountain brush, aspen, and subalpine zones. While these species often develop young stands on the lower and drier sites, they later largely succumb. *Elymus glaucus*, an occasional exception, has shown itself somewhat more capable of growing on relatively drier sites. *Agropyron smithi*, *E. triticoides simplex* (Scribn. and Will.) Hithc. and *Stipa arida* Jones, three very drought-enduring species, have been very difficult to get established and many failures have resulted on all grades of sites. *Poa bulbosa* L. has established itself well on many of the lower foothills but usually dies out after a year or two at higher elevations. *Festuca ovina* L. has failed everywhere except at high elevations where periods of drought are not extended.

Seeds[5] of all 12 species used in these tests were either collected or purchased in 1937 and 1938 and were from the same source supplying most of the experimental plantings.

This investigation is discussed under three subdivisions, *viz.*, (a) germination, (b) emergence, and (c) early development of roots and shoots.

GERMINATION STUDIES

Tests were first made to determine certain latitudes in temperature requirement for germination of the 12 species. Lots of 100 seeds each were tested in triplicate petri dishes under three temperature conditions, *viz.*, (a) alternating temperature (30° C, 6 hours; 20° C, 18 hours); (b) constant temperature (30 ° C); (c) room temperature (mean temperature of 21° C and a range from 19° to 23° C). A fourth test was made of 100 seeds in duplicate petri dishes in a greenhouse with a mean temperature of 14° C and a range from 10° to 40° C.

Differences of only minor importance in the percentage and rate of germination under the four temperature conditions were exhibited by most of the 12 grass species (Table 1). Germination of *A. smithi*,

[5]Seeds as referred to in this paper are the bulbils of *P. bulbosa* and the caryopsis of the other grasses with the commonly attached lemma and palea.

B. carinatus, *E. triticoides simplex*, and *S. arida* was somewhat depressed by the lower greenhouse temperature, while germination of *P. bulbosa* was greatly increased. In general, however, most species showed fair to good germination under all conditions.

TABLE 1.—*Effect of temperature on germination.**

Species	Alternating temperature†		Constant (30° C) temperature		Room temperature‡		Greenhouse temperature§	
	%	Days required	%	Days required	%	Days required	%	Days required
A. cristatum	94	12	94	11	97	10	70	10
A. trachycaulum	96	5	99	7	70	14	97	13
A. smithi	84	25	68	16	6	19	24	18
A. spicatum	95	10	73	12	88	10	88	17
Arrhenatherum elatius	76	10	52	12	68	9	53	22
B. carinatus	85	10	85	13	83	13	46	21
B. inermis	90	10	89	12	89	13	86	19
E. glaucus	96	6	40	30	77	7	79	16
E. triticoides simplex	96	14	77	30	92	13	47	23
F. ovina	83	30	21	30	63	17	74	20
P. bulbosa	13	30	1	24	91	19	98	14
S. arida	86	10	84	8	82	11	43	18

*Tests allowed to run for 30 days.
†30° C for 6 hours; 20° C for 18 hours.
‡Range 19° to 23° C; mean 21° C.
§Range 10° to 40° C; mean 14° C.
Percentages for samples under treatments with in limits of tolerance prescribed (4, 15).

Alternating temperature was found to be the most generally satisfactory for the germination of all species except *P. bulbosa*. *Agropyron smithi* and *F. ovina* showed a high but delayed germination under this condition.

The germination of *A. cristatum*, *A. trachycaulum*, *Arrhenatherum elatius*, *B. carinatus*, *B. inermis*, and *S. arida* was as high under a constant temperature as under alternating temperatures. *Elymus glaucus*, *F. ovina*, and *P. bulbosa* showed a very evident retarded reaction at this temperature.

Room temperature proved as satisfactory as any other for the germination of *A. cristatum*, *A. spicatum*, *Arrhenatherum elatius*, *B. carinatus*, *B. inermis*, *E. triticoides simplex*, and *S. arida*. *Poa bulbosa* responded much better at room temperature than at either alternating or constant temperature but rate of germination was not as fast as in the greenhouse. *Agropyron smithi* gave a very low and much retarded germination in the room temperature.

The widely fluctuating temperature of the greenhouse, which probably more nearly approximates outside conditions in early spring months, either retarded or reduced the germination of most species, except *P. bulbosa* which responded best to this treatment. Three other species, *A. trachycaulum*, *A. spicatum*, and *B. inermis*, gave practically as high germination as in other tests, although rate of germination was somewhat slower. *Agropyron smithi*, *B. carinatus*, *E. triticoides simplex*, and *S. arida* exhibited decided retarded action

when subjected to this widely fluctuating temperature. The data from the greenhouse test suggest that seed of *A. smithi*, *B. carinatus*, *E. triticoides simplex*, and *S. arida* may germinate somewhat more tardily during the early spring months and consequently these species would be at more of a disadvantage than the other species. Of singular significance, however, is the fact that some seed of all species germinated in all the temperature conditions employed.

EMERGENCE STUDIES

The emergence of the germinated seed is the next important step in seedling establishment. To compare the ability of the 12 species in this respect, plantings were made in 12×18×3-inch flats at six depths, *viz.*, surface, ¼, ½, ¾, 1, and 1½ inches. Two blocks were set up and each species and depth was sown with 100 seeds in one sample area (4×12 inches) at random within each block. The experiment was conducted in a greenhouse with a mean temperature of approximately 18° C and with a daily fluctuation from 12° to 32° C during March and April, 1938. The soil was a dark clay loam containing 4.3% organic matter, having a pH of 7.05 and a moisture equivalent of 22%. The soil was moistened daily by sprinkling with a fine spray atomizer.

Inasmuch as this phase of the study was conducted under favorable moisture conditions in a greenhouse, the results probably cannot be applied directly to field conditions where the surface soil rapidly becomes dry. However, it does have application to sites where surface soils do not dry immediately and provides comparative data on rate of emergence. The length of time for emergence of shoots, excluding the surface planting, was in general increased with depth of planting (Table 2). Usually with each increase in depth of ¼ inch delays were noted in the initial emergence of shoots and an increase of ½ inch caused a very pronounced delay. Examination of the seedbed soil at the close of the experiment revealed that at the greater depths most of the seed had germinated, but the shoots had not been able to reach the surface. It is apparent that this ability varied markedly among seeds of the same species as well as between species.

Total emergence 30 days after planting of all species except *Arrhenatherum elatius*, *B. carinatus*, and *E. glaucus* was less from the 1½-inch than from the 1-inch depth. The 1-inch depths produced noticeably less emergence of *A. cristatum*, *F. ovina*, and *P. bulbosa* than did the ¾-inch depth. The ¾-inch depth was apparently too deep for only *F. ovina* and *P. bulbosa*. Low emergence resulted from surface plantings of all species except *A. cristatum*, *B. inermis*, and *P. bulbosa*. This was undoubtedly incident to the drying of the soil between sprinklings, which would indicate that under range conditions where evaporation is high and periods of drought are prolonged surface planting could seldom be expected to produce satisfactory results.

These data also show that within wide limits the species having the heaviest seed can send up shoots from greater depths, although a strict relationship of this kind is not manifest. For example, *B.*

TABLE 2.—*Cumulative percentage of shoot emergence from greenhouse plantings at surface, ¼, ½, ¾, 1, and 1½ inches deep.*

Depth of planting, in.	Species and number of seeds per gram													
	Days after planting							Days after planting						
	5	7	9	11	13	15	30	5	7	9	11	13	15	30
	Bromus carinatus (90)*							*Agropyron trachycaulum* (330)						
Surface	0	0	3	7	12	20	25	6	33	57	64	71	74	75
¼	0	2	83	95	96	96	96	30	83	90	90	92	92	92
½	0	0	73	88	88	90	91	0	69	85	89	89	90	90
¾	0	1	51	85	90	91	91	0	67	89	92	92	92	93
1	0	0	30	85	88	90	90	0	42	81	85	89	89	89
1½	0	1	3	70	91	91	95	0	1	64	75	79	79	81
	Elymus glaucus (190)							*Arrhenatherum elatius* (340)						
Surface	0	10	41	65	73	73	73	0	5	22	25	32	33	35
¼	0	68	87	88	88	89	89	0	12	49	54	59	59	60
½	0	78	93	97	97	97	97	0	11	51	56	58	59	60
¾	0	32	88	92	92	92	92	0	16	64	66	68	68	68
1	0	23	85	89	91	91	93	0	2	53	59	61	61	61
1½	0	0	71	87	91	91	91	0	0	38	49	56	57	58
	Agropyron smithi (215)							*Agropyron cristatum* (570)						
Surface	0	0	6	17	25	30	39	3	14	59	83	87	88	90
¼	0	1	35	61	66	68	72	0	47	86	96	98	98	98
½	0	0	32	62	67	69	70	0	7	73	87	90	90	90
¾	0	0	5	49	66	67	74	0	8	65	83	86	87	87
1	0	0	6	56	60	60	68	0	0	17	68	79	84	87
1½	0	0	1	11	32	43	52	0	0	1	30	56	61	68
	Elymus triticoides simplex (310)							*Stipa arida* (750)						
Surface	0	1	17	28	40	50	62	6	10	34	41	49	51	53
¼	0	9	67	86	87	87	87	0	57	68	72	76	76	77
½	0	18	68	85	90	90	90	0	50	73	79	80	80	80
¾	0	2	52	81	87	87	88	0	40	71	78	81	82	82
1	0	3	43	83	89	91	92	0	19	59	70	71	73	75
1½	0	0	12	54	71	76	78	0	2	19	28	36	37	40
	Bromus inermis (320)							*Poa bulbosa* (950)						
Surface	0	12	34	56	60	69	79	26	64	85	90	93	95	96
¼	0	1	56	77	84	86	89	0	6	47	71	83	87	90
½	0	0	43	76	80	81	85	0	2	26	60	68	73	77
¾	0	0	27	70	74	76	81	0	0	15	49	58	62	64
1	0	0	11	54	66	71	74	0	0	0	5	15	22	28
1½	0	0	1	10	33	43	56	0	0	0	1	2	5	8
	Agropyron spicatum (325)							*Festuca ovina* (1225)						
Surface	0	10	38	48	58	70	78	0	2	25	33	39	41	45
¼	3	59	87	92	94	95	95	0	7	55	63	68	68	69
½	0	29	85	90	91	91	91	0	4	46	58	62	63	63
¾	0	11	60	78	80	80	82	0	1	29	44	51	54	55
1	0	1	62	76	79	80	80	0	0	7	30	36	36	40
1½	0	0	10	32	44	45	50	0	0	1	11	20	24	28

*Numbers in parenthesis refer to seeds per gram as determined by counting 10 grams of pure seed of the seed lots used in these tests.

carinatus and *E. glaucus* species having the heaviest seeds responded as well when planted 1½ inches beneath the surface of the soil as at the ¼-inch depth, while emergence of shoots of lighter seeded species such as *F. ovina*, *P. bulbosa*, and *S. arida* was greatly reduced at the 1½-inch depth. *Festuca ovina* seed, approximately 22% lighter than seed of *P. bulbosa*, however, showed only a slight decrease at the ½- or ¾-inch depths, while the latter demonstrated a very evident reduction in emergence at both of these depths. Likewise *Arrhenatherum elatius* seed, 37% lighter than *Agropyron smithi*, and approximately the same weight as *A. spicatum*, *A. trachycaulum*, *B. inermis*, and *E. triticoides simplex* showed no evident reduction at the 1½-inch depth, while the five named species did. *Agropyron cristatum* and *S. arida* emerged practically as well from the 1½-inch planting as several of the heavier seeded species. The study by Murphy and Arny (9) corroborates these conclusions.

Under the conditions of this experiment ¼ inch was the most generally satisfactory depth of planting. It is reasonable to believe that under conditions of sustained moisture, ¼ to ½ inch should be an adequate depth to plant for most range grasses regardless of size of seed. Where moisture is less dependable and the soil dries rapidly, species should be planted as deep as is consistent with satisfactory emergence.

EARLY SEEDLING DEVELOPMENT STUDIES

To ascertain the comparative rate of root and shoot development some preliminary observations were made in the greenhouse in February and March of 1938, followed by further observations in the field in the spring of 1940. In the greenhouse, flats $12 \times 18 \times 3$ inches were filled with 24 $3 \times 3 \times 3$-inch pasteboard cups. Four blocks, each consisting of three flats placed side by side and containing 72 cups were made up. The cups were filled with a mixture of the dark clay loam previously described and a fine sand in the ratio of 3 parts soil to 2 parts sand. Six cups determined at random within each block were planted to each species at the rate of five seeds per cup at a depth of ¼ inch. At the end of 14 days all plants were pulled out except one in each cup which was to be used for measurement of roots and shoots. Within a species, only those seedlings that emerged on a given day were used. There was a maximum difference of 5 days between species in time of emergence of shoots. Measurements and counts on root and shoots on five plants were taken 14, 17, 21, and 28 days after planting. One block chosen at random out of the four was used at each observation date. Five plants of each species were removed, the soil carefully removed from the roots, and measurements and counts made on leaves and roots.

Over the 28-day period following planting it was obvious that wide differences existed in the rate of elongation of roots between species (Table 3). *Agropyron smithi*, *E. triticoides simplex*, *F. ovina*, and *S. arida* were consistently much slower in the development of roots than other species, while *A. trachycaulum*, *A. spicatum*, *Arrhenatherum elatius*, *B. carinatus*, *B. inermis*, and *E. glaucus* developed at

a much more rapid rate. *Agropyron cristatum* at the end of the 28-day period was in an intermediate position relative to total root development.

TABLE 3.—*Total root length, number of roots, and shoot length per plant in greenhouse.*

Days after planting	Species and days for emergence											
	B. inermis, 7	*A. trachycaulum*, 7	*E. glaucus*, 7	*B. carinatus*, 9	*P. bulbosa*, 5	*Arrhenatherum elatius*, 8	*A. spicatum*, 7	*A. cristatum*, 7	*F. ovina*, 8	*E. triticoides simplex*, 8	*S. arida*, 8	*A. smithi*, 10
	Total Root Length, cm											
14	11	16	14	11	21	13	16	11	7	6	7	7
17	20	50	29	36	38	69	43	20	10	12	11	9
21	87	115	63	88	84	85	68	70	28	23	18	20
28	168	166	166	164	137	126	119	80	71	57	48	46
	Number of Roots											
14	4	8	8	2	16	12	11	3	2	1	1	1
17	18	30	20	26	48	35	32	13	10	4	8	2
21	42	46	26	40	85	46	43	26	23	13	16	10
28	49	53	44	61	108	56	46	29	35	21	25	18
	Shoot Length, cm											
14	4	5	5	3	3	4	5	5	3	3	3	3
17	4	6	6	4	4	5	6	5	3	5	5	3
21	7	8	7	5	5	6	7	7	3	6	5	4
28	7	9	10	7	6	6	9	7	4	7	6	5

Under the conditions of this test, differences in shoot growth between species were much smaller than differences in root growth at the end of the 28-day period.

Because it was recognized that application of greenhouse studies to field conditions might be both difficult and hazardous, observations of root and shoot development were extended to a nursery in which 10 of the species had been planted in the late fall of 1939. Six of the species were planted in two adjacent randomized blocks and four, *A. spicatum*, *B. carinatus*, *E. triticoides simplex*, and *S. arida*, were planted in only one block. The nursery is situated in a mountain brush type at an elevation of 5,375 feet on an easterly exposure. The soil is a deep clay loam. Soil samples taken through 15 cm intervals to a depth of 90 cm on each of the rows showed the soil to be essentially similar at the various depths on all plots. The percentage organic matter ranged from 5.26 at the 1- to 15-cm depth to 1.12 at the 76- to 90-cm depth.

Observations on these field plots were started March 22, 1940, prior to seedling emergence, and continued at 7-day intervals until May 9. A final observation was made 28 days later on June 6 at about the start of the summer drought period. Until June 6 the soil was sufficiently moist for good germination and growth. Emer-

gence and extent of root and shoot development were obtained at each inspection date. Emergence was determined by counting additional shoots as they came up at the intervals mentioned. Root and shoot measurements at successive dates were made on four adjacent plants selected at random on each row. For each species only seedlings that emerged within the same 7-day interval were used. Total length of roots and shoots, total number of roots and shoots, maximum root penetration, and lateral spread of roots were recorded for each plant. Penetration and lateral spread were determined by the trench method described by Weaver (16). After ascertaining spread and penetration, the seedlings were carefully removed from the soil in entirety and counts made on the number of roots and total length ascertained by measuring all the roots and totaling the individual lengths.

Shoot emergence was not observed for any species until March 29, at which time six species had penetrated the soil surface (Table 4).

TABLE 4.—*Percentage emergence of shoots of 10 species based on total number emerged on June 6.*

Species	Date								
	Mar. 22	Mar. 29	Apr. 5	Apr. 12	Apr. 18	Apr. 25	May 2	May 9	June 6
P. bulbosa	0	53	73	93	97	99	100	100	100
A. spicatum	0	47	80	82	93	93	100	100	100
E. glaucus	0	38	71	84	93	98	100	100	100
E. triticoides simplex	0	36	72	90	94	97	100	100	100
A. cristatum	0	42	62	78	90	95	99	100	100
Arrhenatherum elatius	0	37	57	72	88	96	99	99	100
B. carinatus	0	0	0	56	68	82	96	97	100
F. ovina	0	0	0	70	77	81	93	99	100
A. smithi	0	0	0	25	55	71	85	97	100
S. arida	0	0	0	0	10	82	90	91	100

Shoots of *A. smithi*, *B. carinatus*, and *F. ovina* were approximately 2 weeks later than other species in starting to emerge and *S. arida* was more than 3 weeks later. *Agropyron cristatum*, *A. smithi*, *A. spicatum*, *Arrhenatherum elatius*, *E. glaucus*, *E. triticoides simplex*, and *P. bulbosa*, showed differences in time of emergence, but the differences were not great enough to be an important factor in their establishment. It was noted that emergence of all species was continued through a period of weeks, and in some species emergence was taking place as much as 11 weeks after the first shoots appeared. *Agropyron smithi*, *B. carinatus*, *F. ovina*, and *S. arida*, slow in emergence, would obviously be at more of a disadvantage in establishing themselves than other species unless they were capable of developing roots at a more rapid rate immediately after germination.

Of the measurements made on seedling development in the field, total root length, number of roots, and total shoot length displayed greater differences than number of leaves, root penetration, and root spread (Table 5). While differences in penetration and lateral spread

were apparent between certain species, they were not as great as differences in total root length. In general, the species with greatest root length showed a deeper penetration and a wider spread. It is to be noted from Table 5 that generally the quicker developing species had the deeper penetration and wider lateral spread on June 6. Number of roots is quite definitely associated with total root length.

Differences in root elongation were not very apparent until April 18 (Table 5, Fig. 1). At this time *A. spicatum*, *Arrhenatherum elatius*, and *E. glaucus* manifested greater than average total root growth. Root lengths of *A. cristatum*, *B. carinatus*, *E. triticoides simplex*, and *P. bulbosa* were about equal but less than the above three species. *Bromus carinatus*, which had emerged since April 12, displayed a rapid initial development to offset the slow start. *Agropyron smithi* and *F. ovina*, which also had emerged during this last interval, had made little root growth.

By April 25, *B. carinatus* was on a level with *A. spicatum*, *Arrhenatherum elatius*, and *E. glaucus*. The root growth of *A. cristatum* and *P. bulbosa* was somewhat behind these leaders. *Agropyron smithi*, *F. ovina*, and *S. arida* showed a markedly slower root elongation, and *E. triticoides simplex* developed even more slowly. On May 2 the same general relationships were maintained, but by May 9 *A. cristatum* had shown a marked spurt and had a total root length equivalent to the previously faster developing species.

By June 6, after a 28-day interval, some marked changes were evident. *Agropyron cristatum* had a root elongation that was strikingly in excess of all other species (Fig. 2). *Arrhenatherum elatius* and *E. glaucus* were next, but their root growth did not nearly approximate that of *A. cristatum*. *Agropyron spicatum* and *B. carinatus* were together on a lower level. *Agropyron smithi*, *F. ovina*, *E. triticoides simplex*, and *S. arida*, while showing marked increases in total root elongation over previous observations, still lagged behind other species.

Roots of *P. bulbosa* had practically dried up by June 6. Further investigations revealed this to be a characteristic of the species. Subsequent growth depends on new roots which are produced from the bulblets. This peculiarity probably explains the success of this grass on the low foothill areas where it has to compete only with early spring and late fall growing annuals. At higher elevations summer growing species probably keep the surface soil depleted of available moisture and fall growth of *P. bulbosa* is definitely handicapped. Its response to growing conditions in this respect is very similar to that of an annual in that new roots must be formed at each season when growth is renewed.

A comparison of the root elongation of species in the greenhouse and field show that, although the conditions of the greenhouse favored a more rapid root development, the four species *A. smithi*, *E. triticoides simplex*, *F. ovina*, and *S. arida* were the slowest developing species in both environments. *Elymus glaucus*, *Arrhenatherum elatius*, and *B. carinatus* had the most rapid initial root elongation in both tests. While *A. cristatum* showed a slower initial rate of root development than some species under both environments, the field

TABLE 5.—*Total root length, shoot length, number of leaves, number of roots, penetration, and root spread per plant in nursery.*

Date	*A. cristatum**	*E. glaucus**	*Arrhenatherum elatius**	*A. spicatum*†	*B. carinatus*†	*A. smithi**	*F. ovina**	*E. triticoides simplex*†	*S. arida*†	*P. bulbosa**
Root Length, cm										
Apr. 5	5	11	13	7	0	0	0	6	0	10
Apr. 12	10	14	15	9	0	0	0	8	0	10
Apr. 18	12	19	25	20	11	3	4	10	0	14
Apr. 25	29	34	35	38	39	7	8	15	3	30
May 2	36	54	71	56	48	11	13	18	5	41
May 9	83	84	98	79	123	32	22	41	14	73
June 6	1,002	632	579	394	344	186	141	119	32	9
Standard error of June 6 mean	65.69	74.40	69.99	26.42	39.74	15.03	17.61	21.28	8.92	2.00
Shoot Length, cm										
Apr. 5	4	6	7	4	0	0	0	4	0	5
Apr. 12	5	7	9	8	0	0	0	4	0	6
Apr. 18	9	12	11	10	7	3	3	7	0	10
Apr. 25	15	15	21	11	11	7	7	8	3	16
May 2	20	24	26	17	13	10	8	13	6	21
May 9	38	37	41	33	39	18	12	22	10	46
June 6	208	114	127	74	131	44	49	37	29	0
Standard error of June 6 mean	35.92	7.20	20.02	3.63	6.22	4.50	5.60	2.82	3.08	0
Number of Roots										
Apr. 5	3	6	9	2	0	0	0	1	0	9
Apr. 12	7	9	14	3	0	0	0	2	0	9
Apr. 18	11	17	24	13	10	2	5	5	0	28
Apr. 25	27	35	31	30	38	8	7	14	3	35
May 2	30	44	66	29	37	11	16	18	4	37
May 9	56	60	75	39	78	22	21	24	10	70
June 6	888	476	538	264	288	178	170	140	38	6
Standard error of June 6 mean	143.23	56.76	55.34	44.07	40.04	21.28	22.54	19.82	2.91	0.30

Number of Leaves										
Apr. 5	2	2	1	1	0	0	0	1	0	2
Apr. 12	2	2	2	2	0	0	0	1	0	3
Apr. 18	2	3	2	2	2	1	1	2	0	3
Apr. 25	4	3	4	3	3	2	3	3	1	7
May 2	4	5	4	4	3	2	3	3	2	9
May 9	8	8	5	7	7	3	4	3	2	18
June 6	35	19	16	14	14	6	10	8	8	0
Standard error of June 6 mean	4.86	0.27	1.59	0.29	1.11	0.22	1.71	0.22	1.19	0
Root Penetrations, cm										
Apr. 5	5	7	6	4	0	0	0	6	0	4
Apr. 12	6	7	7	6	0	0	0	8	0	4
Apr. 18	5	7	9	13	5	2	3	10	0	5
Apr. 25	10	13	10	14	9	4	4	10	1	6
May 2	12	15	16	17	15	5	5	10	5	8
May 9	18	18	21	29	28	11	6	16	9	12
June 6	45	47	29	54	33	26	12	28	19	0
Standard error of June 6 mean	4.12	2.06	2.14	9.33	4.95	4.00	2.83	5.00	1.12	0
Root Spread, cm										
Apr. 5	1	2	3	1	0	0	0	0	0	2
Apr. 12	1	3	3	1	0	0	0	1	0	2
Apr. 18	2	4	4	3	1	1	0	1	0	3
Apr. 25	4	5	4	4	4	1	1	2	0	7
May 2	5	8	9	9	6	1	2	3	0	6
May 9	10	9	12	9	17	3	2	7	1	9
June 6	22	30	21	24	20	15	10	11	2	0
Standard error of June 6 mean	1.79	2.54	2.16	6.06	1.85	1.21	1.48	3.38	0.18	0

*Each figure based on measurement of eight plants.
†Each figure based on measurement of four plants.

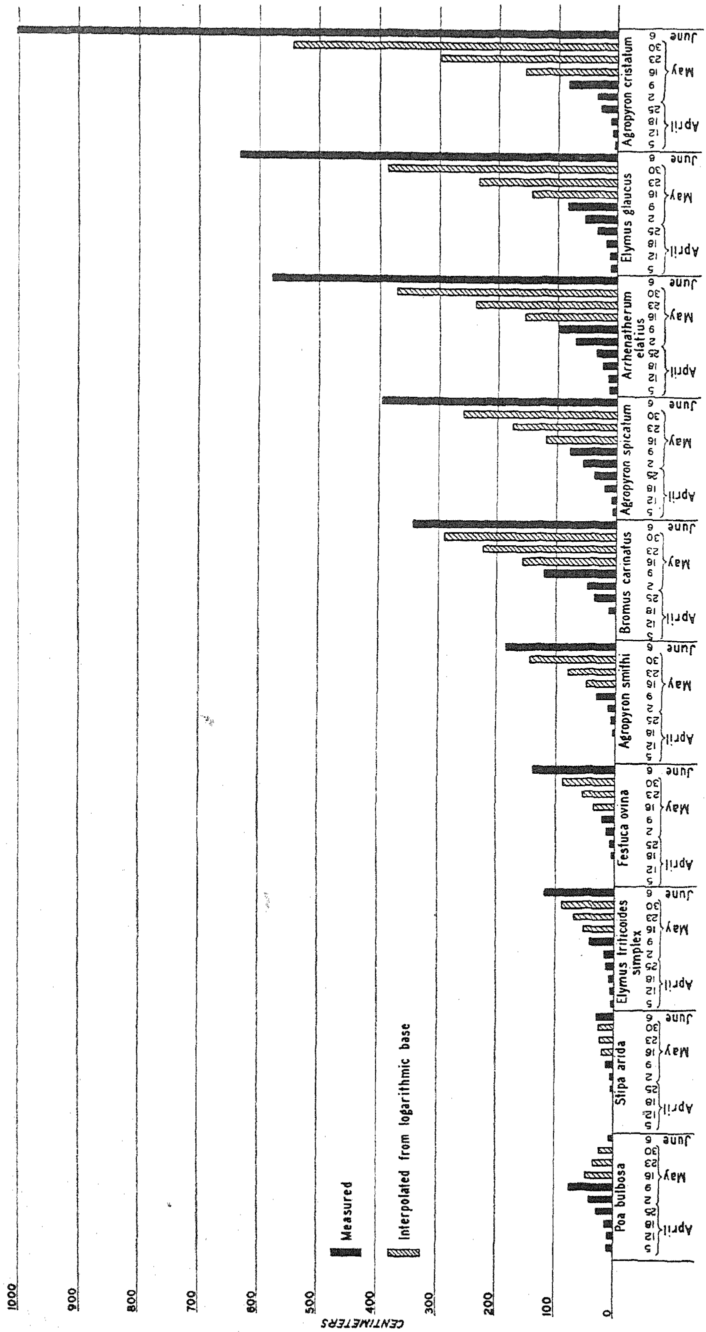

FIG. 1.—Total root growth per plant at 10 weekly intervals. April 5 to June 6.

test, which was continued over a longer period of time, showed that this species overcomes the handicap and prior to the beginning of the dry, hot summer months posesses a total root development much in excess of the other species.

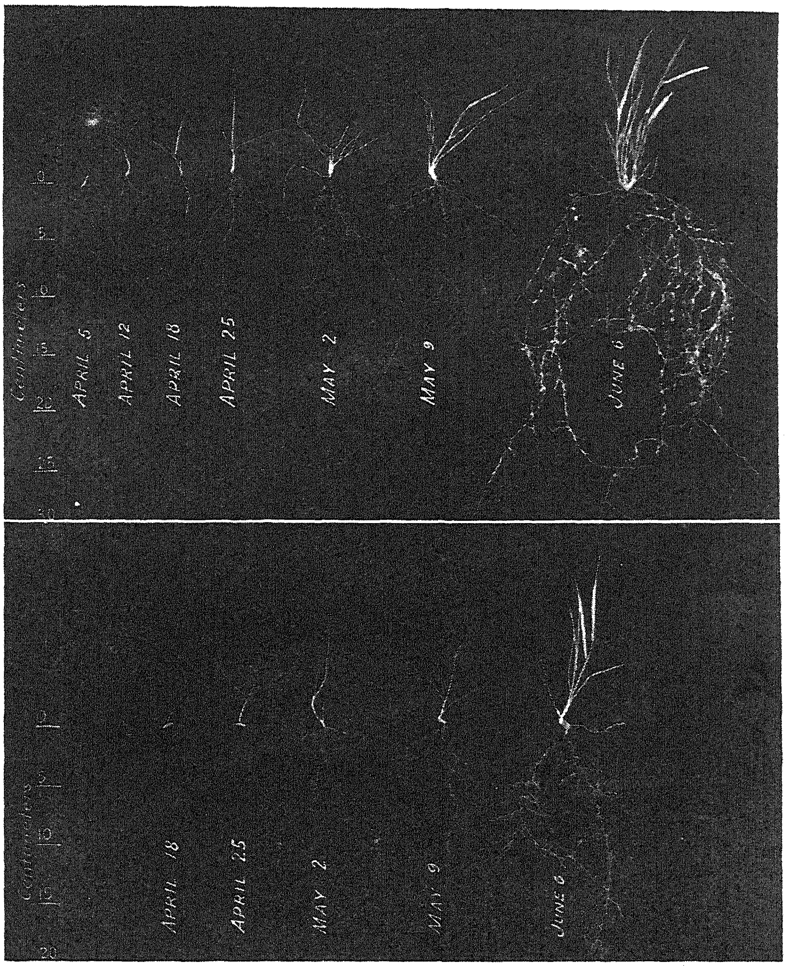

FIG. 2.—Comparative growth of *Agropyron cristatum* (upper) and *A. smithi* (lower). Both species were planted in November 1939. *A. cristatum* emerged March 29, 1940, and *A. smithi* April 12, 1940. By June 6 total root elongation per plant was 1,002 and 186 cm, respectively, and total shoot growth was 208 and 44 cm, respectively.

Differences in shoot growth between most species to May 9 were not nearly so evident as were differences in root growth; however, there was a general positive correlation between rates of root and

shoot development. Between May 9 and June 6 differences in shoot growth became apparent, and by June 6 *A. cristatum* excelled other species with a mean total shoot length of 208 cm, 77 cm in excess of the next closest species. *Bromus carinatus*, *Arrhenatherum elatius*, and *E. glaucus* followed with 131, 127, and 114 cm, respectively, and *A. spicatum* was next with 74 cm. The shoot growth of *F. ovina*, *A. smithi*, *E. triticoides simplex*, and *S. arida* was markedly lower with 49, 44, 37, and 29 cm. The shoots on *P. bulbosa* had completely dried up by June 6. The same general relationships existed in number of leaves as in total shoot length.

On the basis of these seedling development data and success ratings from experimental plot tests it is apparent that a close relationship exists between rate of development of roots of these 12 grass species in the seedling stage and subsequent establishment. The four species *A. smithi*, *E. triticoides simplex*, *F. ovina*, and *S. arida*, with low initial rates of root growth, have been the most difficult species to get established, yet all except *F. ovina* are native to some of the driest sites in the Intermountain region. *Arrhenatherum elatius*, *B. carinatus*, and *E. glaucus* lack extreme drought-enduring characteristics but produce roots at a rapid rate immediately after germination and can successfully establish initial stands on dry sites, although they may later succumb to drought. The more universal success of *A. cristatum* in the Intermountain region is undoubtedly due to a happy combination of inherent drought-enduring characteristics in the mature plant with the ability to develop a sufficient root system in the seedling stage to sustain the young plant through succeeding periods of dry weather.

The reason why some of these drought-enduring species are often found native on sites where repeated artificial seedings have failed is not at once apparent, but it seems likely that such species are dependent on infrequent years of prolonged favorable growing conditions for establishment. Such unusual circumstances may occur only once in every 10 to 15 years. It is emphasized, however, that these observations were conducted under only two sets of conditions and results under other temperatures, soil, and moisture relationships may be considerably different. However, the slow development of seedlings, and especially their root systems, appears as one likely explanation for the frequent failure of some drought-enduring species. Factors other than root development doubtlessly affect the ability of a grass to withstand desiccation. Such factors are beyond the scope of this study.

It is apparent that the capacity of any species to grow in exceptionally dry habitats, or even through a wide range of habitats, and the production of quantities of highly viable seed that will germinate under a variety of temperatures should not be considered as a complete indication of its value for use in artificial reseeding under western range conditions. To make artificial reseeding feasible and within costs commensurate with the value of land, it is necessary to have species available that will establish themselves in at least average years and then continue to grow and propagate through all the climatic hazards to which the site is sub-

jected. Both seedling establishment and drought resistance at maturity are important factors in determining the adaptability of species to reseeding on dry sites. Because of the ease of examining root growth in greenhouse plantings and the apparent similarity of behavior in the field and greenhouse, it appears that test plantings in the greenhouse followed by inspection of roots at various intervals to determine rate of development will furnish a partial basis for the selection of the best species and strains for range reseeding.

SUMMARY AND CONCLUSIONS

A preliminary study of the germination under four sets of temperatures, shoot emergence at six depths of planting in the greenhouse, and rate of development of seedlings in the greenhouse and in the field was made of 12 range grasses, including *Agropyron cristatum*, *A. trachycaulum*, *A. smithi*, *A. spicatum*, *Arrhenatherum elatius*, *Bromus carinatus*, *B. inermis*, *Elymus glaucus*, *E. triticoides simplex*, *Festuca ovina*, *Poa bulbosa*, and *Stipa arida*.

Germination in alternating temperatures of 30° C for 6 hours and 20° C for 18 hours was found to be at least as satisfactory as at a constant 30° C temperature, room temperature between 19° and 23° C, or a mean greenhouse temperature of 14° C which fluctuated between 10° and 40° C, except for *P. bulbosa*, which germinated best in the cooler and widely fluctuating temperature of the greenhouse.

For the most rapid and uniform emergence of shoots ¼ inch was found to be the most desirable depth to plant under the favorable moisture conditions in the greenhouse. The deepest depth, 1½ inches, while not preventing the appearance of shoots in any species, caused a marked reduction in emergence of all species, except *Arrhenatherum elatius*, *B. carinatus*, and *E. glaucus*. Within wide limits, weight of seeds is probably a factor in emergence at the deeper depths, but does not appear to be within narrow ranges. Increases in depth of planting of ½ inch causes evident delays in shoot emergence.

Total root development prior to summer drought appears to be directly associated with initial success or failure. Those species with slow root development, *A. smithi*, *E. triticoides simplex*, *F. ovina*, and *S. arida*, are the species which experimental plantings have shown to be extremely difficult to get started, while *Arrhenatherum elatius* and *B. carinatus*, species which develop roots much more rapidly, establish early stands successfully, although they may later succumb to the rigors of the drier sites where such species as *A. smithi* and *S. arida* would have continued to grow and propagate had they once been able to gain a foothold. The more universal success of *A. cristatum* is attributed in a large part to its ability to produce a greater total root length in the seedling stage than other species.

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A COMPARISON OF CAROTENE, PROTEIN, CALCIUM, AND PHOSPHORUS CONTENT OF BUFFALO GRASS, *BUCHLOE DACTYLOIDES*, AND BLUE GRAMA, *BOUTELOUA GRACILIS*[1]

WRIGHT LANGHAM, WARREN N. MCMILLEN, AND LAMAR WALKER[2]

THE occurrence of severe drought in the Great Plains during the past few years has emphasized the importance of native grasses. Throughout this area buffalo grass and blue grama are the principal native varieties (7).[3] Realization of their importance to the agriculture of the Great Plains area has justified study from every point of view.

Blue grama has been studied extensively. Many observers have reported chemical analysis of this important grass (3, 8, 9, 10, 11, 14, 16, 17), and Stanley and Hodgson (15) in Arizona have made a study of the seasonal changes in its chemical composition. One of the most striking features of a number of these reports is the consistantly low crude protein and phosphorus content of blue grama after maturity and during the dormant period. Watkins (17) has reported that it lost 78% of its phosphorus content as a result of wintering or leaching.

Over a large portion of the High Plains area buffalo grass is much more prevalent than are the gramas. Its drought resistance and adaptability to the tighter soils of the semi-arid southern and central regions have been widely acclaimed (4, 13). Regardless of its prominence, however, relatively few chemical analyses of buffalo grass have been reported.

Furthermore, in the majority of reports of chemical analyses of buffalo grass (3, 5, 8) little or no consideration has been given to seasonal trends in its composition. There also seems to be some question as to the quality of buffalo grass as pasture herbage. One observer (5) has reported that it has been overrated. In another instance (12) its seemingly excellent qualities have been attributed to its confused identity with the gramas.

On the basis of chemical analyses reported in this study, buffalo grass as a source of winter pasture appears to be definitely superior to blue grama. During the growing season, however, there seems to be very little difference in the nutritive quality of the two.

METHODS

Samples of undisturbed buffalo grass and blue grama were obtained from inclosures on the Panhandle A. & M. College experimental farm. The samples were taken by clipping the plants to a height of about ¾ inch above the ground level, using a pair of heavy shears. Sampling was begun in May, 1939, and

[1]Contribution from the Oklahoma Panhandle A. & M. College Agricultural Experiment Station, Goodwell, Okla. Received for publication July 27, 1942.

[2]Experiment Station Chemist, Professor of Animal Husbandry, and former Assistant Station Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 41.

TABLE 1.—*The relationship of seasonal development and wintering to chemical composition of buffalo grass and blue grama.**

Date of sampling	Total moisture, %		Carotene, mg/100 grams		Crude protein, %		Crude ash, %		Calcium, %		Phosphorus, %	
	Buffalo grass	Blue grama	Buffalo grass	Blue grama	Buffalo grass	Blue grama	Buffalo grass	Blue grama	Buffalo grass	Blue grama	Buffalo grass	Blue grama
May 6, 1939†	54.8	60.6	19.4	35.4	13.3	17.0	8.9	9.4	0.40	0.41	0.25	0.24
May 18, 1939	46.6	55.5	17.8	34.4	12.6	14.2	8.9	9.4	0.40	0.43	0.23	0.19
June 5, 1939	43.0	53.3	18.2	34.5	11.0	13.9	9.3	10.4	0.39	0.40	0.18	0.24
June 30, 1939	20.3	46.5	2.6	12.0	8.8	10.1	8.5	9.3	0.28	0.39	0.17	0.18
Aug. 14, 1939	16.7	14.3	2.9	1.2	8.5	7.3	11.3	9.7	0.28	0.20	0.18	0.19
Aug. 28, 1939	12.2	11.4	3.4	1.8	8.7	5.6	11.2	8.2	0.24	0.18	0.20	0.15
Sept. 14, 1939	6.5	7.8	0.0	0.2	8.4	7.6	10.9	8.4	0.33	0.21	0.18	0.15
Oct. 11, 1939‡	5.7	4.2	0.0	0.0	8.3	8.7	10.6	10.2	0.27	0.31	0.15	0.17
Nov. 6, 1939	5.2	6.1	0.0	0.0	7.4	4.4	13.2	8.6	0.27	0.17	0.10	0.08
Dec. 4, 1939	7.4	8.1	0.0	—	7.1	4.6	15.1	9.6	0.33	0.18	0.12	0.08
Feb. 10, 1940	—	—	0.0	—	8.4	4.6	16.2	12.9	0.44	0.35	0.13	0.07
March 4, 1940	8.3	8.7	0.0	—	8.0	4.6	15.5	11.1	0.42	0.33	0.14	0.07
April 16, 1940	6.3	7.2	0.0	—	7.7	5.5	17.4	19.6	0.54	0.54	0.12	0.08
May 15, 1940†	62.4	55.8	34.2	27.1	15.5	13.9	8.7	12.7	0.48	0.47	0.28	0.29
June 1, 1940	62.7	56.7	31.6	24.1	14.6	11.9	10.1	13.5	0.45	0.43	0.30	0.31
June 17, 1940	55.4	55.0	21.6	16.7	12.5	8.8	11.8	14.4	0.46	0.39	0.28	0.23
July 1, 1940	31.7	48.3	5.1	9.9	6.6	7.3	10.5	9.6	0.45	0.31	0.20	0.19
July 15, 1940	13.7	26.4	3.6	4.8	8.3	5.3	11.8	12.0	0.57	0.38	0.21	0.16
Aug. 1, 1940	12.2	18.2	1.5	2.8	7.2	5.5	11.8	15.3	0.48	0.38	0.20	0.14
Aug. 15, 1940	12.8	13.0	4.7	2.9	8.2	5.4	11.1	20.0	0.34	0.38	0.13	0.13
Sept. 2, 1940	14.2	15.0	1.8	2.0	7.6	5.4	10.6	9.5	0.34	0.26	0.14	0.11
Sept. 16, 1940	15.5	13.1	5.4	2.4	8.7	5.1	11.6	9.3	0.29	0.28	0.14	0.10

Oct. 1, 1940	23.6	22.2	2.2	2.7	8.9	4.9	—	—	0.35	0.30	0.14	0.09
Oct. 15, 1940‡	11.3	12.8	—	—	8.1	6.3	16.3	8.9	0.28	0.26	0.13	0.10
Nov. 5, 1940	7.7	8.0	0.0	0.0	8.6	4.8	12.8	9.6	0.31	0.26	0.12	0.09
Nov. 15, 1940	6.2	6.1	0.0	—	8.7	5.4	12.7	11.0	0.31	0.35	0.12	0.09
Dec. 2, 1940	8.0	6.0	—	—	8.5	4.0	15.0	10.6	0.31	0.22	0.12	0.06
Jan. 1, 1941	12.4	10.1	—	—	8.2	3.9	14.5	11.9	0.30	0.29	0.12	0.06
Jan. 16, 1941	19.4	12.8	—	—	8.7	4.1	15.1	15.8	0.35	0.31	0.12	0.06
Jan. 30, 1941	8.5	8.9	—	—	8.3	3.7	14.3	14.9	0.32	0.31	0.13	0.05
Feb. 15, 1941	12.1	6.9	—	—	8.8	3.4	15.0	13.4	0.29	0.27	0.13	0.05
March 3, 1941	10.2	8.2	—	—	8.7	4.2	17.5	15.2	0.37	0.29	0.11	0.05
April 15, 1941	19.3	—	—	—	8.9	4.5	17.5	14.5	0.44	0.34	0.13	0.08
May 15, 1941†	59.6	53.9	30.3	35.8	15.1	13.6	9.7	12.9	0.48	0.47	0.32	0.26
June 1, 1941	66.1	51.1	27.4	23.3	11.7	10.1	10.4	12.2	0.37	0.26	0.24	0.22
June 16, 1941	59.8	52.9	26.1	20.2	10.8	8.6	11.6	12.7	0.30	0.24	0.21	0.20
July 1, 1941	32.6	31.3	9.7	7.5	8.3	6.0	11.9	12.7	0.29	0.31	0.24	0.23
July 15, 1941	49.2	44.0	16.8	15.8	8.8	7.3	9.9	12.5	0.23	0.30	0.19	0.24
Aug. 2, 1941	42.5	35.6	10.3	9.2	9.1	8.3	12.9	12.7	0.28	0.48	0.26	0.25
Aug. 15, 1941	45.2	39.0	9.4	6.7	9.4	6.1	13.8	14.5	0.31	0.35	0.21	0.22
Sept. 1, 1941	39.8	8.5	11.4	8.9	7.6	8.2	15.1	11.7	0.31	0.22	0.22	0.19
Sept. 15, 1941	22.7	20.4	3.6	2.1	6.7	4.7	12.2	12.0	0.30	0.25	0.20	0.21
Oct. 4, 1941	25.0	28.0	3.6	3.0	7.6	4.6	12.5	12.8	0.26	0.17	0.17	0.13
Oct. 17, 1941‡	28.1	23.0	—	—	8.2	5.2	14.2	13.3	0.27	0.19	0.17	0.14
Nov. 5, 1941	6.8	—	—	—	5.8	5.2	13.1	13.1	0.24	0.22	0.16	0.17
Av. all samples before frost	35.1	35.8	13.0	12.9	9.8	8.4	11.0	11.8	0.36	0.33	0.21	0.19
Av. all samples after frost	10.9	9.1	—	—	8.1	4.8	14.8	12.5	0.34	0.29	0.13	0.09
Av. all samples	25.7	26.3	13.0	12.9	9.1	7.0	12.6	12.1	0.35	0.31	0.18	0.15

*All analyses, except moisture, are reported on dry-weight basis.
†First sampling dates of the respective growing seasons.
‡First samples taken after frost date.

continued until November, 1941. During the growing season samples were taken at about 15-day intervals until frost. After frost, samples were taken less frequently during the winter of 1939–40 and at about 15-day intervals during the winter of 1940–41.

All samples were brought to the laboratory at once and weighed and analyzed for total moisture. Those taken during the growing season were analyzed immediately for carotene by the method of Guilbert (6). The samples were then air dried, ground in a Wiley mill, and stored for further analysis. Analyses for total ash and crude protein were according to the A. O. A. C. methods (1). Calcium was determined volumetrically by the oxalate method and phosphorus volumetrically by means of the molybdate procedure. Moisture was determined on the air-dry samples and all analyses calculated to the moisture-free basis.

RESULTS

EFFECT OF SEASONAL DEVELOPMENT AND WINTERING ON CHEMICAL COMPOSITION

The data for both buffalo grass and blue grama are given in Table 1 and show the relationship of seasonable development and wintering to total moisture, carotene, crude protein, crude ash, calcium, and phosphorus content.

The moisture, protein, and phosphorus content of both grasses dropped rapidly during the early part of the growing season as the plants approached maturity. These results are in excellent agreement with the general consensus of opinion as to the affect of maturity on the chemical composition of plants (15). The carotene content also decreased with maturity, which is in agreement with the observations of Watkins (18) for black grama and mesa drop-seed grasses and with Atkeson, *et al.* (2) for buffalo grass.

A consideration of the chemical data in conjunction with the rainfall data given in Table 2 indicates that the principal effect of seasonal rainfall on chemical composition of both buffalo grass and

TABLE 2.—*Record of monthly rainfall at Goodwell, Okla., from May 1, 1939, to Jan. 1, 1942.*

Month	Inches	Month	Inches
May, 1939	1.06	Sept., 1940	1.02
June	3.14	Oct.	0.23
July	2.67	Nov	3.31
Aug.	0.68	Dec.	0.40
Sept	0.03	Jan., 1941	0.30
Oct.	0.25	Feb.	0.43
Nov	0.00	March	0.71
Dec.	0.65	April	1.39
Jan., 1940	0.64	May	5.10
Feb.	0.39	June	3.01
March	0.50	July	4.97
April	1.02	Aug.	1.44
May	5.84	Sept	2.13
June	1.23	Oct.	6.57
July	0.38	Nov	0.07
Aug.	1.12	Dec.	0.22

blue grama is probably through its influence upon the rate of maturity. Carotene and total moisture, however, may be influenced more directly by the amount of precipitation.

The most striking fact revealed by the data in Table 1 was the superior quality of buffalo grass over blue grama during the winter months. The average crude protein content of all samples of blue grama taken after frost was 4.8% compared to 8.1% for buffalo grass.

The phosphorus and calcium content of buffalo grass was also appreciably higher than that of blue grama during the dormant period. The average calcium content of all winter samplings of buffalo grass was 0.34% as compared to 0.29% for blue grama. The average phosphorus content of all samples of buffalo grass taken after frost date was 0.13%. This is above the minimum satisfactory value of 0.113% phosphorus established by Watkins (17) for New Mexico grasses. Most samples of blue grama taken after frost contained less than 0.113% phosphorus and averaged 0.09%. These results indicate rather definitely that buffalo grass is a better source of phosphorus, crude protein, and calcium during the winter months and that it is less subject to loss from wintering or leaching.

Averages of the analyses of all samples taken before frost indicated little difference in buffalo grass and blue grama during the summer season. The only significant difference was in crude protein. Buffalo grass averaged 9.8% crude protein as compared to 8.4% for blue grama.

EFFECTS OF CLIPPING ON CHEMICAL COMPOSITION

Meter square plots of buffalo grass and blue grama were clipped at various time intervals during the growing season. The purpose of the experiment was to check the effect of previous clippings on composition. Beginning June 1, 1939, the No. 1 plot of each variety was clipped monthly for as many months as growing conditions permitted. The No. 2 plot was clipped on May 15, July 15, and September 15, beginning in 1939. The No. 5 plot was clipped at 2-month intervals, beginning June 1, 1940. For comparison, upon each sampling date samples were taken from areas that had received no previous clipping. All samples were taken to the laboratory immediately and analyzed as described previously. Some of these analyses are given in Table 3.

This experiment has not been conducted over a sufficient period of time to have much quantitative value, and the variability of weather conditions in the Southern High Plains area makes any set clipping or grazing schedule impractical and hard to follow. The data in Table 3, however, indicate that the moisture, carotene, crude protein, crude ash, and calcium content of buffalo grass may be affected very little by a reasonable amount of clipping. Blue grama, however, seems to be affected more than buffalo grass. The moisture, carotene, crude protein, ash, calcium, and phosphorus content of blue grama seems to be increased appreciably by clipping. A slight increase in the phosphorus content of buffalo grass also occurred as a result of clipping. Similar increases as a result of

TABLE 3.—*Effect of clipping on chemical composition of buffalo grass and blue grama.*

Description	Buffalo grass						Blue grama					
	Total moisture, %	Carotene, mg/100 grams	Crude protein, %	Crude ash, %	Ca %	P %	Total moisture, %	Carotene, mg/100 grams	Crude protein, %	Crude ash, %	Ca %	P %
Plot No. 1												
July 1, 1940 2nd cutting	38.1	10.9	7.5	11.9	0.44	0.27	55.1	14.5	8.3	11.2	0.36	0.25
July 1, no previous cutting	31.7	5.1	6.7	10.5	0.45	0.20	48.3	9.9	7.3	9.6	0.31	0.19
June 1, 1941 1st cutting	57.1	21.0	9.8	9.5	0.37	0.28	55.8	25.0	10.3	13.9	0.41	0.31
June 1, no previous cutting	66.1	27.4	11.7	10.4	0.37	0.24	51.1	23.3	10.1	12.2	0.26	0.22
July 1, 1941 2nd cutting	33.0	11.3	9.5	13.2	0.36	0.31	34.3	10.7	9.4	13.8	0.38	0.31
July 1, no previous cutting	32.6	9.7	8.3	11.9	0.29	0.23	31.3	7.5	6.0	12.7	0.31	0.22
Aug. 1, 1941 3rd cutting	45.7	15.1	10.1	12.9	0.35	0.29	43.1	14.5	9.1	14.3	0.46	0.40
Aug. 1, no previous cutting	42.5	10.3	9.1	12.9	0.28	0.27	35.6	9.2	8.3	12.7	0.49	0.25
Plot No. 2												
July 15, 1940 2nd cutting	16.1	4.3	7.2	11.8	0.43	0.25	34.5	6.7	6.9	10.9	0.41	0.19
July 15, no previous cutting	13.7	3.6	8.3	11.8	0.57	0.21	26.4	4.8	5.3	12.0	0.38	0.16
July 15, 1941 2nd cutting	46.9	14.9	8.8	10.5	0.27	0.21	47.2	15.7	7.3	13.9	0.31	0.26
July 15, no previous cutting	49.2	16.8	8.8	9.9	0.23	0.19	44.1	15.8	7.3	12.5	0.31	0.24
Sept. 15, 1941 3rd cutting	21.8	8.8	6.9	13.8	0.33	0.28	19.3	2.7	5.8	13.9	0.29	0.20
Sept. 15, no previous cutting	22.7	3.6	6.7	12.2	0.31	0.20	20.4	2.1	4.7	12.1	0.25	0.21
Plot No. 5												
Aug. 1, 1940 2nd cutting	6.7	0.0	9.0	11.2	0.34	0.18	18.9	4.6	8.8	15.2	0.44	0.16
Aug. 1, no previous cutting	12.2	1.5	7.2	11.8	0.47	0.20	18.2	2.8	5.5	15.2	0.38	0.14
June 1, 1941 1st cutting	61.8	25.4	12.6	10.1	0.36	0.26	57.9	26.2	11.7	12.2	0.29	0.27
June 1, no previous cutting	66.1	27.4	11.7	10.4	0.37	0.24	51.1	23.3	10.1	12.1	0.26	0.22
Aug. 1, 1941 2nd cutting	46.0	12.2	9.8	13.7	0.32	0.25	45.9	9.3	7.2	13.2	0.30	0.21
Aug. 1, no previous cutting	42.4	10.3	9.1	12.9	0.28	0.27	35.6	9.2	8.3	12.7	0.48	0.25
Av. all samples previous cutting	37.3	12.4	9.1	11.9	0.36	0.26	41.2	13.0	8.5	13.3	0.37	0.26
Av. all samples no previous cutting	37.9	11.6	8.8	11.5	0.36	0.23	36.2	10.8	7.3	12.4	0.34	0.21

frequency of clipping were observed by Hopper and Nesbitt (8) for a number of North Dakota grasses. In pasture management problems small variations in chemical composition as a result of frequency or intensity of cutting or grazing may be minor compared to the effects of climatic factors and intensity of grazing on total yield of grass. Obviously, the effect of intensity or frequency of grazing on total yield of grass is of primary interest. Studies of this nature are being made at the Panhandle Agricultural Experiment Station.

SUMMARY

The moisture, carotene, crude protein, crude ash, calcium, and phosphorus content of buffalo grass (*Buchloe dactyloides*) and blue grama (*Bouteloua gracilis*) have been determined at intervals during the period from May, 1939, to November, 1941. Moisture, crude protein, carotene, and phosphorus were high in both grasses during the early stages but decreased rapidly as the plants approached maturity. Calcium was quite variable in both varieties throughout the growing season.

The average of analyses of all samples taken after frost showed buffalo grass to be much higher in crude protein, crude ash, calcium, and phosphorus than was blue grama. This has been interpreted as indicating that buffalo grass makes better winter pasture and suffers less loss of nutrient material as a result of wintering or leaching than does blue grama.

The chemical composition of buffalo grass seems to be affected less by previous clipping than that of blue grama. As a factor in pasture management for the Southern Great Plains area, the effect of frequency or intensity of grazing on chemical composition may be insignificant in comparison with the effect of the variability of weather conditions and grazing on total yield of grass.

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WHAT EFFECT DO COMMERCIAL FERTILIZERS HAVE ON THE MATURITY OF CORN?[1]

H. C. RATHER AND J. TYSON[2]

"ONE of the marked effects of fertilizer on corn is that the maturity of the crop is materially hastened." The quoted statement might be drawn from scores of scientific papers or it might essentially reflect the opinion of thousands of corn growers. We have no argument with the many who have arrived at this conclusion. We merely think it is of interest to point out that for 3 years we have laid out experiments, using four replications, in randomized blocks, in the hope of significantly altering the maturity of three different corn hybrids with variations in fertilizer treatments. We did not succeed.

The data were analyzed statistically, but the average moisture contents of the corn, within a variety, were so close together and the slight variations were so inconsistant as to make it obvious that the fertilizers used in these trials had had no practical influence on maturity.

Although the chief objective of these experiments was to study corn maturity, yield determinations were also made. In two or three instances yield responses due to the use of some particular fertilizer were statistically significant, but in no case in these trials were yield responses highly profitable.

MATERIAL AND METHODS

These experiments were conducted on Conover silt loam soil which contained a high proportion of organic matter and lime. The soil reaction ranged from pH 7.0 to 7.5. Some high spots in the field contained sufficient carbonates to effervesce freely with dilute hydrochloric acid. The supply of available phosphorus and potassium was very low as indicated by soil and plant tissue tests and by deficiency symptoms.

Each plot consisted of two rows of corn. The fertilizer was applied in bands on a level with and 1½ inches to one side of the seed. The lengths of the plots varied from year to year but were never less than 100 feet. The left row of each plot was used for moisture samples. Ten ears a plot were picked at random from each replication. These were weighed and dried down for moisture determinations. The final moisture sample in each season was based on the weighing and drying of a sample of at least 50 ears from each plot, taken from the right hand row which was harvested for yield.

The same fertilizer treatments were used the first two years. After these disappointing results some unusual nitrogen and potash applications were included the third year in an effort to vary maturity even though the effect might be one of delay.

[1]Contribution from the Departments of Farm Crops and Soils Science, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 598 (New Series). Received for publication July 27, 1942.

[2]Professor of Farm Crops and Associate Professor of Soil Science, respectively.

DISCUSSION

The data on maturity and yields are presented in Tables 1, 2, 3, and 4. The data do not indicate that there was absolutely no effect of fertilizers on corn maturity, but rather that the effect was largely insignificant from a practical standpoint. For example, 200 pounds an acre of 4-16-8 does appear to have resulted in corn of somewhat lower moisture content rather consistently, more so than any other fertilizer. However, if we apply the average moisture loss per day of each variety to the average difference in moisture content between the corn receiving no fertilizer and that receiving 200 pounds an acre of 4-16-8, it is indicated that Michigan 1218 was hastened in maturity, as an average for the 3 years, by 1.6 days, Wisconsin 606 by 2.3 days, and Indiana 416 by 2.5 days.

Likewise, in 1941, 200 pounds an acre of 0-0-50, compared with no fertilizer delayed the maturity of Michigan 1218 by 4.5 days, of Wisconsin 606 by 1.7 days, and of Indiana 416 by 1.4 days. With the doubtful exception of apparent delay in Michigan 1218 resulting from potash, such variations in maturity, even if real, should make no essential differences to a corn grower in the handling of his crop.

There was no lack of response to fertilizer by way of increased top growth early in the season. At the end of June the corn on the

TABLE 1.—*Influence of commercial fertilizer on the maturity of corn as indicated by the moisture content of the ears.*

Treatment	Average percentage moisture content of ears covering a period from early September to late October				
	1939	1940	1941	1939–40 av.	1939–40–41 av.
No treatment	45.9	50.5	49.0	48.2	48.5
100 lbs. 0–16–0	46.1	49.7	—	47.9	—
200 lbs. 0–16–0	46.1	50.1	48.3	48.1	48.2
100 lbs. 0–16–8	45.9	50.0	—	48.0	—
200 lbs. 0–16–8	44.6	49.1	48.0	46.9	47.2
100 lbs. 4–16–8	44.7	48.8	—	46.8	—
200 lbs. 4–16–8	44.1	48.8	47.9	46.5	46.9
200 lbs. 10–16–0	—	—	47.8	—	—
200 lbs. 0–0–50	—	—	50.4	—	—
200 lbs. 10–0–10	—	—	50.7	—	—
200 lbs. 20–0–0*	—	—	49.7	—	—

*Split applications applied as 50-pound side dressings at four different times.

TABLE 2.—*Influence of rate of application of 0–16–8 on the maturity of Indiana hybrid No. 416.*

Treatment	Average percentage moisture content of ears in the fall		
	1939	1940	1939–40 av.
No treatment	50.8	56.3	53.6
100 lbs. 0–16–8	51.2	55.3	53.3
200 lbs. 0–16–8	49.7	55.2	52.5
350 lbs. 0–16–8	49.5	54.9	52.2

TABLE 3.—*Influence of the commercial fertilizer treatment on corn yield expressed in bushels per acre at 15.5% moisture.*

Treatment	Yield, bushels per acre				
	1939	1940	1941	1939–40 av.	1939–40–41 av.
No treatment	44.2	40.9	46.8	42.6	44.0
100 lbs. 0–16–0	42.2	41.6	—	41.9	—
200 lbs. 0–16–0	44.0	41.8	49.9	42.9	45.2
100 lbs. 0–16—8	46.5	40.5	—	43.5	—
200 lbs. 0–16–8	44.4	43.1	49.7	43.8	45.7
100 lbs. 4–16–8	42.0	42.9	—	42.4	—
200 lbs. 4–16–8	44.7	40.1	53.5	42.4	46.1
200 lbs. 10–16–0	—	—	49.2	—	—
200 lbs. 0–0–50	—	—	55.4	—	—
200 lbs. 10–0–10	—	—	49.1	—	—
200 lbs. 20–0–0*	—	—	52.9	—	—

*Split applications applied as 50-pound side dressings at four different times.

TABLE 4.—*Influence of rate of application of 0–16–8 on the yield of Indiana hybrid No. 416.*

Treatment	Yield, bushels per acre		
	1939	1940	1939–40 av.
No treatment	48.0	46.6	47.3
100 lbs. 0–16–8	51.2	43.6	47.4
200 lbs. 0–16–8	46.8	50.2	48.5
350 lbs. 0–16–8	55.5	51.7	53.6

fertilized plots appeared definitely more vigorous than that which received no fertilizer. These marked differences were no longer apparent after the corn tasseled out. The noteworthy exception was the series of plots receiving 200 pounds per acre of 0-0-50 in 1941. The corn on these plots appeared backward early in the season, yet this fertilizer treatment proved fairly promising with respect to yield on this soil and in this droughty season. Its apparent effect of slightly delaying maturity was unimportant in this case.

Possibly the weather was a factor which limited the effectiveness of the fertilizer. Weather conditions in the different seasons were such as may be expected under Michigan conditions. Temperatures and precipitation in relation to normal are given in Table 5. July is Michigan's warmest month, the month in which moisture loss by evaporation is generally greatest. Also, in the 3 years under consideration, there was a deficiency in July rainfall of from 1.26 to 2.30 inches. The early increased top growth response to the fertilizer may have been an actual disadvantage during dry hot July. The slowly growing corn fertilized with potash in 1941, which made relatively good showing in yield, tends further to indicate no advantage from increased early top growth under the conditions of the experiment.

TABLE 5.—*Temperature and precipitation at East Lansing, Mich., during the corn growing seasons of 1939, 1940, and 1941 compared with normal.*

Month	Normal	Departure		
		1939	1940	1941
	Temperature, °F			
May	56.9	+3.4	−2.1	+3.1
June	66.4	+1.7	0	+1.7
July	70.9	+0.3	+0.3	+0.8
August	68.5	+1.5	0	−0.1
September	61.4	+2.2	−1.0	+3.0
October	50.3	+0.6	0	+2.6
	Precipitation, Inches			
May	3.42	−1.35	+1.24	−0.14
June	3.51	+0.26	+2.19	+0.19
July	3.10	−1.50	−1.26	−2.30
August	2.82	−0.85	+6.39	+0.04
September	2.91	−1.50	−1.49	+0.05
October	2.47	+1.13	+1.11	+4.86

That different fertilizers did not markedly influence the maturity of corn in these trials does not preclude the probability that the different soils may have variable effects on maturity just as they so obviously do on yield. In 1940 the soil of the different blocks used for this experiment did have a differential effect on the maturity of the corn that was much more marked than was the influence of any fertilizer treatment. The variation in the maturity of the corn in the different blocks is brought out in Table 6. The data in this table represent the average performance of all corn in each block or replicate without respect to variety or fertilizer treatment.

TABLE 6.—*Variation in the maturity of the corn in the different replicates of the 1940 experiments.*

Item	Block 1	Block 2	Block 3	Block 4
No. days from planting to 50% silking	63.1	65.2	65.3	67.6
Moisture Sept. 12, %	62.0	64.9	65.0	67.8
Moisture Sept. 23, %	49.1	50.3	51.7	54.6
Moisture Oct. 2, %	46.2	48.2	49.0	52.1
Moisture Oct. 12, %	40.7	41.8	42.3	45.0
Moisture Oct. 22, %	38.9	39.3	40.9	41.5
Yield, bu. per acre	43.2	42.2	42.9	37.9

The consistency of the data indicating the delayed maturity of the corn in block 4 as compared with that in block 1 eliminates the possibility of this being a mere chance variation. This difference in maturity of about 4 days at silking time amounted to nearly 8 days in the fall. The lower yields in block 4 were largely due to the failure of Indiana 416 and Wisconsin 606 to mature before frost. Michigan 1218 matured thoroughly and showed no significant

yield differences in the different blocks. Noteworthy differences in replicates were evident only on the soil area used for these trials in 1940.

The differences in maturity between the varieties used in these trials are given in Table 7.

TABLE 7.—*Variation in the maturity of the corn hybrids used in these trials as calculated from average moisture contents in the fall and average rates of moisture loss.*

Variety	Number of days later than Michigan 1218		
	1939	1940	1941
Wisconsin 606	5.6	6.2	6.0
Indiana 416	11.2	16.3	15.2

CONCLUSIONS

There are many conditions under which commercial fertilizer does not materially affect the maturity of corn nor profitably increase its yield.

When fertilizer is used on corn a pronounced increase in growth is often seen in the early part of the summer. In agricultural practice observations of this initial stimulus may frequently give rise to unduly optimistic estimates of actual yield and maturity differences at harvest time.

Many corn growers may well find it more profitable to maintain the mineral plant nutrients in their soils by applying commercial fertilizer to crops other than corn.

GERMINATION OF MAIZE UNDER ADVERSE CONDITIONS[1]

L. A. TATUM AND M. S. ZUBER[2]

A GOOD stand is one of the first essentials in the production of maximum yields of any crop. Poor stands with maize are most frequent when planting is followed by a period of cold wet weather which favors the development of pathogens at the expense of the seed or young seedlings. Although weather is of prime importance in such poor stands, it has been observed repeatedly that different lots of seed perform very differently under comparable conditions. Stand difficulties of this sort seem to have increased following the artificial drying and centralized processing which came about with the development of the hybrid corn industry. This suggests that some of the processing operations may be responsible. Further indications that processing may be of major importance are the differences in germination of samples of the same hybrid from different producers. It has been observed that seed from some producers rather consistently gives poor stands while that from others tends to give good stands. The results presented in this paper were obtained in an attempt to evaluate some of the factors which may influence the germination obtained under unfavorable conditions and to relate these factors to processing procedures.

LITERATURE

The problem of germination and stand in corn has been studied from several points of view. Only those papers most pertinent to the present work will be considered. Meyers (4)[3] pointed out the relation between pericarp injury and germination of maize under unfavorable conditions. He found that broken pericarps resulted in reduced stands in the field when the soil was wet and cold. He also found that inoculation with spore suspension of *Penicillium* sp. reduced the germination of samples with pericarp injury more than that of those without injury. Hottes (1) pointed out the importance of an intact seed coat when wheat is germinated under unfavorable conditions. Koehler (2) has considered the importance of breaks in the pericarp over the crown as openings for the entry of pathogens. Koehler and Dungan (3) found that corn grown from commercial bin-dried seed yielded less on the average than that from hanger-dried seed. They found more crown pericarp injury, more broken off tip caps, and more minor injuries in the bin-dried samples and suggested that the greater injury might be responsible for the lower yields from bin-dried seed. Tatum (5) found that apparently minor injuries over the germs of corn kernels were as serious as much more obvious injuries to other parts of the kernel. He found that exposure to low temperatures in steamed soil did not result in decreased germination,

[1]Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, in cooperation with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Journal paper (J-1031) of the Iowa Agricultural Experiment Station. Project 163. Received for publication August 22, 1942.

[2]Junior Plant Breeder and Agent, respectively, Division of Cereal Crops and Diseases, Collaborators, Agronomy Section, Farm Crops Subsection, Iowa Agricultural Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited", p. 59.

indicating that soil pathogens were responsible for the lower germination percentages of injured samples. Previous work thus indicates an important relation between pericarp injury and ability to germinate under unfavorable conditions.

MATERIALS AND METHODS

The corn seed samples were subjected to a "cold-test" germination test which consisted of planting them in wet field soil and holding them at a temperature of approximately 45° F for 7 days. They then were moved to a higher temperature to complete germination.

Pericarp injury was determined by examining 100 kernels under 10× binoculars. With this magnification it was possible to detect most of the breaks, although some of them could be seen only when light struck them from the proper angle. Any kernel showing one or more breaks or cracks in the pericarp *over the germ* was considered damaged. The percentage of injured kernels in the sample was determined in this manner, with no distinction made for type or severity of damage. Some injury undoubtedly was overlooked.

Samples were taken at different stages in the processing procedure and the percentage of injured kernels determined to locate the source of pericarp injury. Samples were shaken in a large tin can to simulate rough handling. In some cases susceptibility to injury was determined by dropping to a concrete floor from different heights.

Data were obtained in 1941, in connection with the Iowa State Corn Yield Test, on the relation of cold-test germination percentage and pericarp injury to field performance. Samples of seed to be planted in the yield test comparisons were given a cold test by the Iowa State College Seed Laboratory. All possible correlations were calculated for the three variables, cold-test germination percentage, field stand, and yield. Multiple correlations of yield with cold-test germination percentage and field stand also were calculated. The seed for the yield tests was treated with New Improved Semesan Junior before planting.

EXPERIMENTAL RESULTS

PERICARP DAMAGE AND COLD-TEST GERMINATION

Preliminary studies had indicated an important relation between pericarp injury over the germ and cold-test germination percentage but further data were needed to establish the degree of relationship. Information as to the extent of such damage in seed being sold also was needed. In connection with the Iowa State Corn Yield Test and the seed certification program many samples were obtained from producers or salesmen and they were subjected to cold-test germinations by the Iowa State College Seed Laboratory. These samples should fairly well represent the seed being sold in Iowa.

On the basis of cold-test germination data, 50 samples were chosen to represent the range in susceptibility to cold-test injury. These samples included a disproportionate number of those with low cold-test germination percentages. Pericarp injury determinations were made on 100 kernels of each sample. Figs. 1 and 2 illustrate four examples of damage frequently found.

These pericarp breaks usually can be seen only with difficulty and many of them not at all without magnification. Those illustrated are of the most serious type but often are not the ones found most

frequently. In some samples, particularly those with a large percentage of injured kernels, there are relatively few clear-cut breaks, but instead many kernels have frayed or crushed areas which result from impacts in dropping against a hard surface.

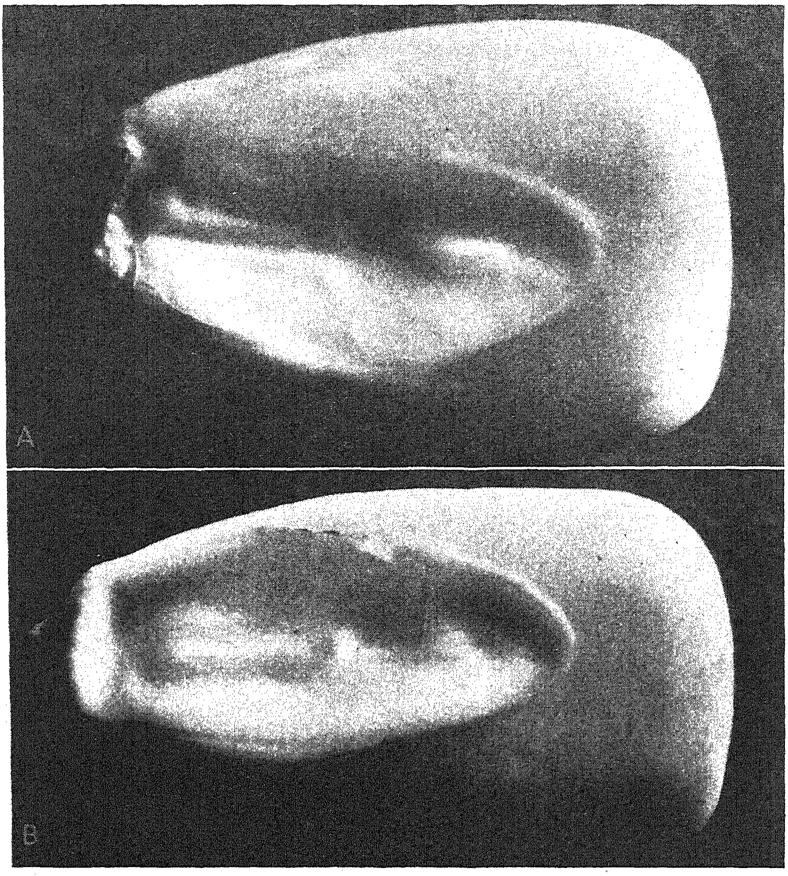

FIG. 1.—A, type of injury produced when kernels are dropped against a hard surface; B, common type of injury which may have occurred during either shelling or dropping.

Data on pericarp injury and on germination percentages under cold-test and normal procedures are presented in Table 1. Examination of the data reveals a high negative correlation between the percentages of kernels with pericarp injury over the germ and cold-test germination percentages ($r = -.81$). Because of the arbitrary classification as damaged of any kernel with an injury over the germ, without regard to type or number of breaks, such a high correlation is surprising. Data presented below show that some kinds of injury

are more serious than others and that damage other than that over the germ is important. These results make it seem highly probable that many of the poor stands in the field are the results of planting seed with damaged pericarp.

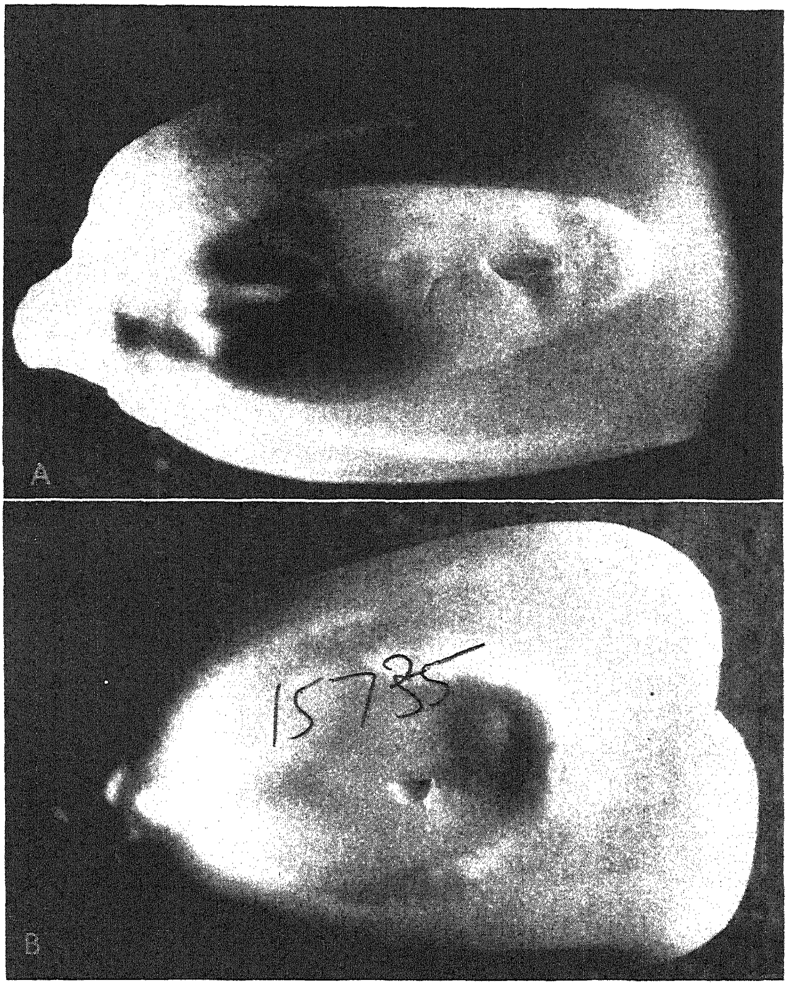

FIG. 2.—A, injury which probably is due to impact against another kernel; B, injury of a type which occurs during shelling.

TYPES OF PERICARP DAMAGE AND THEIR RELATIVE IMPORTANCE

The relative frequencies of various types of injuries varied greatly among the samples of commercial seed examined. It seemed desirable, therefore, to compare the germinating ability in a cold-test of samples receiving different kinds of artificial damage. For such a test, samples

with the crushed type of injury were obtained by shaking in a metal container. Samples with the clear-cut break type of injury were obtained by breaking the pericarp directly over the germ with a dissecting needle and by cutting the pericarp at one edge of the germ with a knife. Injury resembling somewhat that obtained in shaking, but localized at the tip of the kernel, was obtained by scraping with a dull knife. A very severe kind of crown injury was obtained by cutting off the pericarp with a considerable portion of crown starch. It is unfortunate that a sample with less severe crown injury was not included to represent more nearly the condition which is actually encountered in commercial seed.

TABLE 1.—*Percentages of kernels with damaged pericarp and germination percentages under cold-test and normal conditions.*

Damaged, %	Germination, %		Damaged, %	Germination, %	
	Cold-test	Normal		Cold-test	Normal
0	99	97	21	89	96
2	94	96	21	88	95
3	93	100	30	98	100
4	96	97	32	58	97
5	100	100	35	72	99
5	67	91	35	67	96
6	97	99	36	67	96
7	99	98	43	77	100
7	97	100	44	61	96
8	97	99	52	40	94
9	99	98	55	67	100
9	99	99	56	41	99
9	99	99	57	53	97
9	91	98	65	60	100
11	96	99	66	41	97
11	74	93	67	87	95
12	99	99	70	59	94
13	95	97	83	27	95
14	99	100	86	57	98
15	94	96	88	68	97
16	97	100	92	61	96
16	77	96	92	30	95
18	97	99	94	53	98
19	75	95	95	67	98
20	76	97	98	31	100

Four replications of 25 kernels from each sample were subjected to the cold-test germination test. The results are presented in Table 2. The data for the individual replications are given in order to show the extent of variability in the cold tests. The sum of the number of kernels germinating in the four replications is equal to the average germination percentage for each sample since a total of 100 kernels were tested in each case.

TABLE 2.—*Number of kernels germinating in the cold test of samples receiving different kinds of damage.*

Sample	Kind of damage	Number of kernels germinating				
		Replication				Sum
		1	2	3	4	
U. S. 13	Shaken 10 times, 50% injured kernels	15	22	17	21	75
	Shaken 20 times, 85% injured kernels	16	15	19	14	64
	1 puncture per kernel over germ	7	11	6	2	26
	2 punctures per kernel over germ	3	5	3	2	13
	Tip of each kernel scraped on germ side	18	21	22	14	75
	Pericarp cut at one edge of germ	10	12	14	12	48
	Crown pericarp and part of starch cut off	16	10	15	15	56
	Undamaged	24	25	24	24	97
Iowa 3110	Shaken 20 times, 38% injured kernels	14	20	22	23	79
	1 puncture per kernel over germ	6	4	13	7	30
	Tip scraped on germ side	15	13	9	8	45
	Undamaged	23	23	24	25	95
Iowa 939	Shaken 20 times, 22% injured kernels	22	18	24	22	86
	1 puncture over germ	5	7	5	7	24
	Tip scraped	8	5	7	8	28
	Undamaged	22	25	24	24	95

Difference necessary for significance at 5% level = 14.8%.

Results of this test illustrate in a striking manner the importance of pericarp injury in relation to germination under cold-test conditions. The seriousness of pericarp breaks seems to depend largely upon how open and direct are the passageways they provide for pathogens to reach the embryos.

FIELD TESTS

The data presented thus far leave little room for doubt as to the importance of pericarp injuries over the germ in reducing germination following the cold-test treatment. To complete the picture, data showing the relation of cold-test germination percentage to field performance are now presented. These data were obtained in connection with the 1941 Iowa Corn Yield Tests which were planted at 12 locations as shown in Fig. 3.

In Table 3 correlation coefficients (r values) of stand with cold-test germination percentage, yield with stand, yield with cold-test germination percentage, and the multiple correlation coefficients (R values) of cold-test germination percentage and stand with yield are shown for each district.

Except for district 2 the correlations of stand with cold-test germination percentage were highly significant, indicating the usefulness of a laboratory cold-test germination test in the evaluation of seed for planting under field conditions. The portion of the variation in stand which is directly associated with variation in cold-test

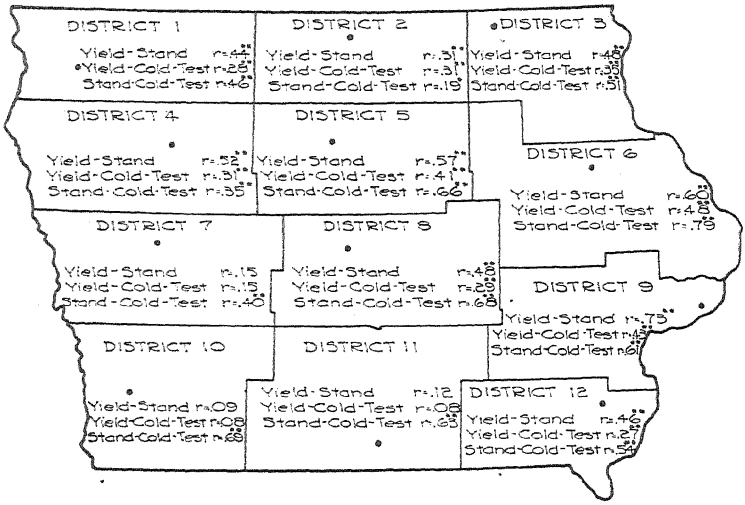

FIG. 3.—Location of the 1941 Iowa Corn Yield Test Fields with the correlations between yield and stand, yield and cold-test germination percentage, and stand and cold-test germination percentage.

germination percentage may be obtained by squaring r. Since environmental conditions differed widely for the different districts, the importance of cold-test germination percentage would be expected to differ, and such was the case. The range was from 12% in district 4 to 62% in district 6. The district 6 plot was planted in a wet field and cold, wet weather prevailed for several days following planting, while the district 4 plot was on a rather sandy, well-drained soil and the weather following planting was more favorable.

TABLE 3.—*Correlation coefficients (r) of stand with cold-test germination percentage, yield with stand, yield with cold-test germination percentage, and multiple correlation (R) of cold-test germination percentage and stand with yield.*

District	Degrees of freedom	Stand-cold test, r	Yield-stand, r	Yield-cold test, r	Stand and cold test with yield, R
1	109	0.46*	0.44*	0.28*	0.45*
2	109	0.19†	0.31*	0.31*	0.41*
3	109	0.51*	0.48*	0.35*	0.50*
4	130	0.35*	0.52*	0.31*	0.54*
5	130	0.66*	0.57*	0.41*	0.57*
6	130	0.79*	0.60*	0.48*	0.60*
7	105	0.40*	0.15	0.15	0.18
8	105	0.68*	0.48*	0.29*	0.52*
9	105	0.61*	0.73*	0.43*	0.74*
10	90	0.69*	0.09	0.08	0.10
11	90	0.63*	0.12	0.08	0.12
12	90	0.54*	0.46*	0.27*	0.46*

*Indicates significance at 1% level.
†Indicates significance at 5% level.

The correlations of yield with cold-test germination percentage and of yield with stand were highly significant, except in districts 7, 10, and 11. The absence of significant relations for these fields might be expected as other factors, such as drought and chinch bug infestation, play a predominant role in determining yields in those areas of the state.

In 11 of the 12 districts the multiple correlations of stand and cold-test germination percentage with yield are very nearly the same as the simple correlations between stand and yield. This indicates that, in general, seed injury reflected in the cold-test germination percentage also is reflected in the field stand which in turn affects yield. Evidently the argument that soil pathogens are important in reducing yield by weakening plants does not hold for these data, except in district 2. Only in this district was the partial correlation of cold-test germination percentage with yield significant.

It should be emphasized that for each sample normal germination tests had shown good viability. Since the seed used in these tests was treated with fungicidal dust, there is evidence that such treatment is not an adequate control measure. Dust treatment may help, but certainly a more dependable and direct approach would be to prevent the pericarp injury during processing.

PROCESSING AND COLD-TEST GERMINATION PERFORMANCE

In Table 4 are presented average cold-test and normal germination percentages of the seed samples from 19 producers, the producers being designated by numbers.

TABLE 4.—*Average cold-test germination percentages on hybrid seed from different producers in order from highest to lowest.*

Producer	Number of hybrids	Average cold-test germination, %	Average germination, normal test, %
1	6	98.0	99.2
2	13	97.5	97.8
3	3	96.3	98.7
4	7	95.9	99.2
5	4	95.5	99.7
6	8	95.0	95.0
7	8	94.3	97.4
8	3	90.3	98.3
9	8	86.5	97.9
10	4	86.3	96.5
11	10	85.2	95.4
12	5	84.2	95.6
13	4	74.3	98.0
14	8	74.3	97.3
15	5	73.6	98.3
16	5	73.6	97.6
17	6	70.3	98.2
18	2	67.5	98.0
19	7	47.3	96.8

There was a strong tendency for seed from some producers to germinate well following the cold-test while that from others germinated poorly. In view of the correlation between pericarp injury and cold-test response this would be expected. It is probable that the processing procedure is essentially the same for all seed handled in a given plant. A method of handling or processing which damages one lot of seed would be expected to damage other lots which are handled in a like manner. These data may not be conclusive in showing that processing methods are an important factor, for in many cases different hybrids were produced. However, for hybrids which are widely grown it is possible to compare the results of different producers using the same kind of corn. Data on three such hybrids are presented in Table 5. It is evident that differences in the pedigrees of the corn grown do not entirely account for the differences between producers shown in Table 4. There is an indication, however, that Iowa Hybrid 939 is less susceptible to damage than either 931 or 942.

TABLE 5.—*Cold-test germination percentages for three hybrids as influenced by production methods.*

Producer	Iowa 931, %	Iowa 942, %	Iowa 939, %
1	—	—	89
2	41	—	61
3	—	—	100
4	58	53	90
5	—	—	88
6	—	89	—
7	91	—	—

FACTORS CONTRIBUTING TO PERICARP INJURY

Preliminary studies on factors contributing to pericarp injury point to shelling as an important source, but elevating, dropping, and grading also are important. Sampling at different stages of processing has shown that the damage is cumulative. Any impact between the seed and a hard surface or object damages a portion of the kernels so that the final sample exhibits damage sustained at a number of steps during processing. The most important source of damage very probably differs from plant to plant. Certain types of damage are characteristic of different operations in processing. The injuries in samples from some processing plants are predominantly of the type resulting from dropping or impact against a hard surface. Samples from other plants show a higher percentage of the kind of damage which occurs in shelling. It is impossible to make a general statement as to where the injury occurs because plant designs and equipment are so different.

Data on the source of damage during processing are presented in Table 6. These data show that the damage does not all occur in any one operation. The difference between samples of Iowa 3110, which differed only in moisture content when processed, is especially interesting. Dropping samples with different moisture contents to a

hard surface or shaking in a metal container gave results indicating that moisture content during processing is a most important factor. Above 14% moisture there was relatively little injury, but it increased with the drier samples. The same treatment which gave 3 to 4% injury at 14% moisture produced 70 to 80% injury at 8% moisture. The difference very probably is due to increased brittleness of the pericarp in the drier samples. Because of the difficulty in changing methods of processing in plants already in operation, control of moisture would seem to offer a more feasible solution to the problem. A change in certification regulations to permit the highest possible moisture content for safe storage in sacks might be advisable.

TABLE 6.—*Effect of handling on percentage of kernels injured and on normal and cold-test germination percentages.*

Sample	Treatment	Germination, %		Kernels injured, %
		Normal	Cold test	
1, Iowa 939	Hand shelled	100	93	0
2, Iowa 939	Machine shelled and elevated to bin	98	83	4
3, Iowa 939	Machine shelled, through specific gravity cleaner, and to bottom of storage bin	99	79	11
4, Iowa 3110	Hand shelled at 7.6% moisture	97	95	0
5, Iowa 3110	Machine shelled, elevated to bin, 7.6% moisture	97	77	16
6, Iowa 3110	Machine shelled, through specific gravity cleaner to bottom of bin, 7.6% moisture	96	73	19
7, Iowa 3110	Same as (6) but at 12% moisture	99	83	9

Difference in cold-test germination percentages necessary for significance at 5% level = 9.8.

Observations on the relation of maturity at harvest to susceptibility to injury show that immature samples are most subject to damage. The majority of the injuries to such samples is near the kernel tip as might be expected since that is the last part of the seed to complete its development. In addition to the more fragile pericarp on immature seed there is a tendency for such samples to wrinkle and blister during drying which seems to increase the likelihood of injury.

A few comparisons have suggested that strains differ in ease of injury and many observations on kernel anatomy and pericarp texture would lead one to expect such differences. Seed with a sunken germ and smooth seed coat are particularly less susceptible to damage from dropping than seed with a protruding germ and wrinkled seed coat.

DISCUSSION

Seed-coat injuries over the crown have been found by previous investigators to result in decreased stand and yield. The present studies confirm the work showing harmful effects from crown injury

but show that inconspicuous injuries over the germ may be much more important.

Samples which are hand shelled and not subjected to any mechanical treatment are free of injuries and germinate approximately the same in a cold test as in a normal test. Commercial seed, however, suffers a greater or lesser amount of pericarp injury, depending upon processing methods. This pericarp injury is reflected in reduced germination under cold-test conditions. The close relationship which has been found to exist between pericarp injury over the germ and ability to germinate under cold test conditions shows clearly the importance of preventing injury during processing. As most of the injury occurs during shelling and subsequent operations in processing, some modifications in seed handling might well be considered. All unnecessary drops and points of impact between the kernels and hard surfaces should be eliminated. In some cases a partial remodeling of the plant may be necessary. Where they are unavoidable, points of impact between the kernels and hard surfaces should be cushioned with some material to absorb the shock. Consideration should be given to developing shellers which would produce less injury.

A factor which seems to be very important and which could be controlled rather easily is the moisture content at which the corn is shelled and handled. In many cases corn is dried to a moisture content as low as 8 or 9% before shelling and grading. The data indicate that a more desirable procedure would be to dry it only sufficiently for safe storage.

One obstacle in improving the situation is in convincing producers of the necessity for care in handling the seed, beginning at harvest and including the handling of the finished product in bags. If the seed is very dry, a surprisingly slight shock will produce injury. The injuries are so inconspicuous that it sometimes is difficult to realize that they are occurring.

The ability of some companies to produce seed which is relatively free of injuries indicates that reasonable precautions and care are all that is necessary.

CONCLUSIONS

There was a close relation between inconspicuous pericarp injury over the germ and stand and yield in the field. The seriousness of a break depended upon how direct an opening it provided for pathogens to reach the embryo.

The percentage of the kernels with pericarp injury was dependent to a large extent upon processing methods. Each operation in which the seed was handled, particularly those involving a drop against a hard surface, contributed to the injury.

A low moisture content of the seed during shelling and other operations greatly increased the amount of injury.

Fungicidal dust treatment was not an adequate means of preventing poor stands in the field. More effective was the use of seed with an intact pericarp.

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A COMPARISON OF THE ACTUAL YIELD OF DOUBLE CROSSES OF MAIZE WITH THEIR PREDICTED YIELD FROM SINGLE CROSSES[1]

H. K. Hayes, R. P. Murphy, and E. H. Rinke[2]

THE first extensive study in corn of methods of estimating the yields of double crosses was made by Jenkins (4)[3] who used the yields of single and top crosses in prediction. He concluded from this study that, "inbred variety crosses may be utilized to advantage in estimating the performance of double crosses among these lines." One of the methods tested by Jenkins, called method B, consisted of averaging the yields of four of the six possible single crosses from any four inbred lines, not using in this average the two single crosses used as parents of a particular double cross. The predicted yields obtained by this method were no more highly correlated with the actual yield of the double cross than they were when the predictions were based on the yields of all six possible single crosses from four lines.

Doxtator and Johnson (2) later showed that method B could be used very well to determine which two single crosses, among four inbred lines, should be used as the parental single crosses in order to give the highest yielding double cross combination out of the three such possible double cross combinations. They demonstrated that some double cross combinations from the same four inbred lines yielded significantly more than others. Anderson (1) gave further proof that this method of predicting the yield of a double cross could be used to determine which double cross combination from four inbred lines would give the highest yield. He compared the actual yield with the predicted for 15 double crosses and obtained a highly significant r value of +.90.

From these results it was concluded that the predicted yield by Jenkins' method B could be used as an estimate of the actual yield with a high degree of precision. This method has been used extensively at Minnesota since 1938 in making the first estimate of the yielding ability and period of maturity of double crosses.

The present study is a comparison of (a) the relative yields of selected double crosses based on prediction data by method B during one season and the performance of these same double crosses in later seasons, and (b) a comparison of actual yields of double crosses and their predicted yields from single crosses grown with the double crosses.

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[3]Figures in parenthesis refer to "Literature Cited", p. 65.

MATERIALS AND METHODS

The material for the first phase of the study was a part of that used in the regular corn breeding program in Minnesota. After obtaining inbreds by the methods that have been described previously by Hayes and Johnson (3), Johnson and Hayes (5), and Wu (6), these were tested in top crosses as a basis for the selection of inbreds with high combining ability. Inbreds not closely related and of similar dates of maturity were crossed in all combinations.

The single crosses were tested in randomized blocks replicated three times at each of two or more locations. Five kernels were planted per hill and thinned to a stand of three plants. The yields were computed on the basis of harvesting perfect stand hills surrounded by corn. Standard recommended double crosses of known performance were grown as checks and predicted double crosses by method B were selected in comparison with the checks on the basis of yield and moisture content at harvest. By using two double crosses as checks, one of early and another of later maturity, the probable section of the state where a predicted double cross could be used to advantage was fairly accurately determined.

Selection of predicted double crosses was made by retaining predicted doubles that yielded about as well as the standard doubles of similar moisture content. The predicted doubles gave wide differences in yield. Predicted double crosses were selected if the single crosses used in prediction were relatively similar in moisture content, appeared desirable in agronomic characters, and if the predicted yield did not deviate from the check by more than two times the standard error of a difference. In this phase of the program, the same error was used for predicted as for actual double crosses. It was obtained by multiplying the error for the mean of an individual hybrid by $\sqrt{2}$.

The double crosses were tested in randomized blocks in comparison with standard checks at four locations, with four replications at each location. The rate of planting was three kernels per hill and no correction was made for differences in stand. Standard errors were computed for these trials in the usual way.

In 1938 single cross trials in southern Minnesota were carried out in randomized blocks at two locations, at the Waseca branch station and in Faribault County, with three replications at each location. Of the 67 predicted double crosses from these studies, 21 were tested as actual double crosses in 1939 at five locations in North Central Minnesota while 46 were again grown in southern Minnesota. A part of the lack of agreement between predicted and actual double crosses may be explained by the fact that comparisons were included for yields in different maturity zones. These are included because they illustrate the method of selection that in general seems highly satisfactory. The other 47 predicted double crosses included in the study were tested as single crosses at four locations in central or northern Minnesota in either 1938 or 1940 by the method described for trials at Waseca and in Faribault County. The tests of these 47 actual double crosses were made at four locations in either 1940 or 1941 in central and northern Minnesota.

Yields and moisture content of predicted and actual double crosses were placed in percentages of standard double crosses of similar moisture content used as checks. This made it possible to combine all comparisons in the same tables.

In the second phase of the study the materials used were grown in two different groups. Three early double crosses and the single crosses necessary for their prediction were grown in randomized blocks with five replications at each of four locations. A similar test was made of five late double crosses and the single crosses necessary for their prediction.

In addition, a late double cross, (CII × C14) × (A374 × A375), was tested in a similar manner in connection with another study. The four single crosses necessary for the prediction and the double cross were grown in randomized blocks for three replications at each of three locations.

The standard errors of the means of the actual double crosses were calculated by the analysis of variance. The standard errors of the means of predicted hybrids for yield and moisture were determined by dividing the S. E. of a mean by $\sqrt{4}$, since four single crosses were averaged to obtain a predicted double. The standard error of a difference was obtained from $\sqrt{\text{S.E. (predicted)}^2 + \text{S. E. (actual)}^2}$.

EXPERIMENTAL RESULTS

A comparison of predicted with actual double cross yields given in Table 1 includes only those predicted doubles that were selected for further study, that seemed about equal or superior to the standard double crosses in yield and moisture content at maturity, and that appeared relatively desirable in agronomic characters. The hybrids selected have been placed in classes based on + or − 1 to 5 times the calculated level of significance at the 5% point in comparison with the checks. A large percentage of the predicted hybrids appeared undesirable and these were not grown as actual doubles. There were 114 comparisons, 6 of these being duplicated, where predicted yields in 1939 and in 1940 were each compared with actual yields of doubles in 1941. The other comparisons were for 102 different predicted doubles in one season and actual doubles in another. In these 114 comparisons only the better prediction and actual double cross combination for any four inbreds was used in the study.

TABLE 1.—*Comparative yield of predicted and actual double crosses in relation to standard double crosses, in classes of + and − 1, 2, 3, etc., × the level of significance.*

Predicted yield classes in + or − 1, 2, 3, etc., × the level of significance	Actual yield classes in + or − 1, 2, 3, etc., × the level of significance: −2	−1	0	+1	+2	+3	+4	Total
−2	1							1
−1	1	2	9	4				16
0		4	7	17	6	5		39
+1	1	2	7	14	5	1		30
+2		1	1	7	10	3	1	23
+3					2	1	2	5
Total	3	9	24	42	23	10	3	114

$r_{xy} = 0.4847$ (sig. r at 1% pt. = 0.2540).

Even though only the most desirable predicted double crosses were selected to test as actual doubles the correlation coefficient between the yield of predicted and actual double crosses was +0.4847, where a significant r at the 1% point is 0.2540.

A similar comparison was made for moisture content of predicted and actual double crosses. A part of the lack of relationship as given in Table 2 is without doubt due to the fact that 21 predicted double

crosses made from tests in southern Minnesota were tested as actual doubles in central and northern Minnesota.

A significant and positive correlation for the moisture content of predicted doubles and actual doubles of 0.2142 was obtained.

TABLE 2.—*Comparative moisture percentages of predicted and actual double crosses in relation to standard double crosses in classes of + and − 1, 2, 3, etc., × the level of significance.*

Predicted moisture classes in + or − 1, 2, 3, etc., × the level of significance	Actual moisture classes in + or − 1, 2, 3, etc., × the level of significance											
	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	Total
−3					1							1
−2	1	1			1		1					4
−1	2		2	2	5	7	4	7	2	1		32
0	1	3	2	9	8	21	8	3	2			57
+1				2	3	3	2	1	1			12
+2				1		1	1		1			4
+3					1		1					2
+4								1				1
+5											1	1
Total	4	4	4	14	19	32	17	12	6	1	1	114

r_{xy} = 0.2142 (sig. r at 5% pt. = 0.1946).

The yield and moisture percentage at harvest of the predicted double crosses and of the actual double crosses grown in the same trial for the second phase of the study are given in Table 3.

After the appropriate errors for the various differences were considered, it was found that two out of nine differences for moisture and one of nine for yield were highly significant. In addition one yield difference reached the 5% point.

While these results lead to the conclusion that there are statistically significant differences between the predicted and actual yields, certainly these differences are very small from the practical standpoint. As noted in Table 3, there were three hybrids tested in the early group. One of these yielded much more than the other two and also had a significantly higher moisture content at husking. In the late group of five hybrids the highest yielder as a predicted double also yielded best as an actual double and the lowest yielding predicted hybrid was also the lowest yielding as an actual double. The relative rank, yield, and moisture content of the other hybrids was very similar in both predicted and actual doubles. These results give further evidence to show that the method of predicting the yield and moisture content of a double cross from an average of four singles, using the four singles that are not parents of a particular double cross, is a very desirable method of predicting the actual yield of a double cross.

TABLE 3.—*Yield and moisture percentages of predicted double crosses and of actual double crosses and the differences between them with their respective errors.*

Hybrid	Predicted		Actual		Difference, predicted—actual	
	Yield, bu.	Moisture, %	Yield, bu.	Moisture, %	Yield	Moisture
Early						
(A96 × A148) × (A116 × A131)	53.4±0.58	24.2±0.15	51.1±1.15	25.2±0.29	+2.3±1.29	−1.0±0.33†
(A96 × A158) × (A116 × A131)	54.6±0.58	24.5±0.15	49.9±1.15	24.9±0.29	+4.7±1.29†	−0.4±0.33
(A357 × A392) × (A334 × A344)	67.2±0.58	29.3±0.15	69.1±1.15	28.8±0.29	−1.9±1.29	+0.5±0.33
Late						
(A334 × A348) × (A25 × A322)	77.7±0.66	24.7±0.16	75.5±1.31	24.4±0.32	+2.2±1.47	+0.3±0.36
(A25 × A334) × (A375 × A348)	80.7±0.66	25.4±0.16	79.8±1.31	25.4±0.32	+0.9±1.47	0.0±0.36
(A25 × A71) × (A111 × A158)	67.3±0.66	22.9±0.16	64.4±1.31	22.7±0.32	+2.9±1.47*	+0.2±0.36
(A25 × A111) × (A71 × A158)	62.6±0.66	23.6±0.16	63.6±1.31	23.2±0.32	−1.0±1.47	+0.4±0.36
(A25 × A158) × (A71 × A111)	63.3±0.66	23.2±0.16	66.0±1.31	22.2±0.32	−2.7±1.47	+1.0±0.36†
(C11 × C14) × (A374 × A375)	76.7±0.88	24.4±0.25	74.6±1.76	24.0±0.49	+2.1±1.97	−0.5±0.55

*Reaches the difference required for odds of 19:1.
†Exceeds the difference required for odds of 99:1.

SUMMARY

Since 1938, the predicted yield and moisture content of double crosses has been obtained at Minnesota by averaging the performance of four of the six single crosses that can be made between four inbred lines, not using in the average the two single crosses used as parents of a particular double cross. A comparison of the yield and moisture content of 114 such selected double crosses grown as a part of the regular plant breeding program was used to test the desirability of the method. Of these 111 gave actual yields that fell within −1 to +4 of the level of significance, at the 5% point, when compared with available recommended double crosses. As a plant breeding technic the method of selection seems highly reliable.

The actual yield and moisture content of eight double crosses was compared with their predicted performance from trials with five replications at each of four locations made the same season. An additional hybrid was tested in a separate trial with three replications at each of three locations. There were two cases for moisture content and one for yield of highly significant differences and one for yield that reached the 5% point. These are more than expected on the basis of chance alone. From the practical standpoint, however, there was excellent agreement between the predicted and actual double crosses in yield and moisture content. Differences in yield and moisture content between predicted and actual doubles were not so large that they would greatly affect the relative performance of hybrids.

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THE ACCURACY OF INCOMPLETE BLOCK DESIGNS IN VARIETAL TRIALS IN WEST VIRGINIA[1]

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SINCE 1938, various incomplete block designs have been used in yield trials of different varieties of crops in West Virginia. A balanced lattice design with nine varieties and four replications has been used in testing hybrid corn throughout the state in cooperation with county agricultural agents and farmers. A similar design with 16 varieties and five replications has been used in testing varieties of tobacco and soybeans at the Lakin experimental farm, and since 1940 lattice square designs involving 25 and 49 varieties have been used quite extensively for corn yield trials on the state experimental farms.

From a study of uniformity data Yates (5)[3] has reported an increase of from 20 to 50% in efficiency over ordinary randomized blocks by the use of incomplete block designs. Goulden (2), also from a study of uniformity data, reports similar increases in efficiency, the increases being partially correlated with soil heterogeneity. Cochran (1) in yield trials with corn in Iowa has shown that for lattice square designs the increase in accuracy over randomized blocks represents a saving of about one replication in six with 25 varieties, one replication in five with 49 or 81 varieties, and one replication in three with 121 varieties. Zuber (9) using corn uniformity trial data compared lattice designs assuming 25, 49, 81, and 121 varieties with ordinary randomized blocks occupying the same plots. He shows an average gain of 36% in favor of the lattice designs calculated with recovery of inter-block information.

So far little or no information has been presented concerning the accuracy of incomplete block designs with less than 25 varieties. It is the purpose of this paper to present primarily the accuracies obtained in West Virginia with 60 corn varietal yield experiments designed as balanced lattices with nine varieties each in comparison with randomized blocks occupying the same plots and replications. Also, data are presented to show the efficiency of balanced lattice designs with 16 varieties and the lattice square designs with 25 and 49 varieties relative to randomized blocks.

BALANCED LATTICE DESIGNS WITH 9 VARIETIES, 4 REPLICATIONS, 12 INCOMPLETE BLOCKS

DESIGN AND VALIDITY OF COMPARISONS

In 1938, a cooperative program between the West Virginia Agricultural Experiment Station and Extension Division for testing

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[3]Figures in parenthesis refer to "Literature Cited", p. 75.

yields of hybrid corn in various counties of the state was started. The trials with nine varieties were set up according to the balanced lattice design with nine varieties and four replications described by Goulden (3). The design as laid down in the field is shown in Fig. 1.

I	II	III	IV
6	3	8	1
5	9	4	6
4	6	3	8
9	8	5	7
7	2	1	3
8	5	9	5
1	7	2	9
2	4	6	4
3	1	7	2

FIG. 1.—A diagram of one of the balanced lattice designs used with nine varieties and four replications. The four rectangles marked I, II, III, and IV represent the four complete blocks or replications. Each complete block containing all varieties is divided into three equal incomplete blocks containing three varieties each in 2 by 10 hill plots.

Each complete replication containing nine varieties was divided into three incomplete blocks with three varieties each in 2 by 10 hill plots. The varieties were assigned to the incomplete blocks in such a manner that each variety throughout the experiment occurs with every other variety once in the 12 incomplete blocks. For example, in the first replication containing all nine varieties, variety 1 occurs in an incomplete block with varieties 2 and 3. In the second replication it appears in an incomplete block with varieties 4 and 7 and so on with varieties 5 and 9 and 6 and 8 in the third and fourth replications, respectively. The varieties assigned to an incomplete block were randomized within that block and the incomplete blocks were randomized within a complete block.

Except for the restrictions pointed out above, the design is similar to an ordinary randomized block experiment and may be correctly analyzed as such. The arrangement of the plots gives a fairly compact shape of the complete block which usually is desirable in a randomized block design. The arrangement, therefore, permits an equitable comparison between the two designs.

METHOD OF ANALYSIS

In calculating the balanced lattice designs, the new method of analysis of recovering inter-block information, as first proposed by Yates (7, 8) for certain incomplete block designs, was used. The

writer, however, is indebted to W. G. Cochran, Statistical Laboratory, Iowa State College, Ames, Iowa, for adaptation of the method to the balanced lattice with nine varieties. An example of the method of computation is illustrated below.

The yield data in pounds per plot obtained from one of the balanced lattice designs with nine varieties are presented in Table 1, together with some of the necessary calculations. The yield data are classified according to varieties, incomplete blocks, and complete blocks. For example, incomplete block No. 1 contained varieties 1, 2, and 3 with yields of 18.6, 19.5, and 22.4 pounds, respectively; incomplete block No. 2 contained varieties 4, 5, and 6 with yields of 15.7, 14.3, and 19.9 pounds, respectively; and so on for the rest of the blocks. Incomplete blocks Nos. 1, 2, and 3 make up the first replication; Nos. 4, 5, and 6 the second; etc. Incomplete block totals and replication totals are given at the bottom of the table. Variety totals are given in the column headed V with the grand total at the bottom.

The components of the analysis of variance are shown in Table 2.

The total sum of squares and sums of squares for replications and varieties (unadjusted) are obtained as in an ordinary randomized blocks analysis. Before the sum of squares for blocks within replications (adjusted) can be obtained, two values, SB and W, must be computed for each variety. For any specific variety SB = sum of the totals of the incomplete blocks in which the specific variety occurs. For example, variety 1 occurs in incomplete blocks Nos. 1, 4, 7, and 10. For variety 1, therefore, SB = 60.5 + 59.6 + 65.4 + 61.7 = 247.2. Variety 2 occurs in incomplete blocks Nos. 1, 5, 9, and 11. For variety 2, SB = 60.5 + 60.7 + 74.1 + 58.1 = 253.4. The values of SB for each of the varieties are given in Table 1. The W values for each variety may be calculated from the formula $W = kV - (k + 1)\,SB + G$, where G is the grand total or 749.4 and k is the number of plots per incomplete block, or 3 in this example. Thus, $W = 3V - 4SB + G$. V and SB, of course, refer to the variety total and SB value, respectively, for the specific variety for which W is being computed. The value of W for variety 1, for example, is $3(85.4) - 4(247.2) + 749.4 = +16.8$. The sum of the W's should be zero.

The sum of squares for blocks within replications adjusted is the sum of the squares of the W's divided by $(k + 1)k^3$ or $\dfrac{(16.8)^2 + (8.9)^2 + \ldots (28.0)^2}{108} = 78.37$. The sum of squares for intra-block error can be readily obtained by subtraction after the total and values for the other three components are computed.

Next the weighting factors w and w′ must be calculated in order to adjust varietal totals. These may be calculated from the formulas $w = \dfrac{1}{M}$ and $w' = \dfrac{k}{(k + 1)M' - M}$. M is the intra-block error mean square and M′ is the mean square for blocks adjusted. Thus w =

TABLE 1.—*Yield of dry shelled corn in pounds per plot classified according to varieties, incomplete blocks, and replications.*

Variety No.	Incomplete blocks												Variety totals	Block totals for each V	3V−4SB +G*	Adjusted total V+λ W/3
	1	2	3	4	5	6	7	8	9	10	11	12	V	SB	W	Adj. V
1	18.6	—	—	19.6	—	—	25.1	—	—	22.1	—	—	85.4	247.2	+16.8	86.3
2	19.5	—	—	—	21.5	—	—	—	25.4	—	18.7	—	85.1	253.4	− 8.9	84.6
3	22.4	—	—	—	—	26.1	—	22.5	—	—	—	29.5	100.5	269.8	−28.3	99.0
4	—	15.7	—	18.0	—	—	—	22.7	—	—	19.4	—	75.8	233.4	+43.2	78.1
5	—	14.3	—	—	21.6	—	21.2	—	—	—	—	26.6	83.7	260.7	−42.3	81.4
6	—	19.9	—	—	—	16.4	—	—	23.6	21.6	—	—	81.5	244.5	+15.9	82.3
7	—	—	17.1	22.0	—	—	—	—	25.1	—	—	28.6	92.8	268.5	−46.2	90.3
8	—	—	19.0	—	17.6	—	—	20.6	—	18.0	—	—	75.2	238.3	+21.8	76.4
9	—	—	14.0	—	—	16.3	19.1	—	—	—	20.0	—	69.4	232.4	+28.0	70.9
Incomplete block totals	60.5	49.9	50.1	59.6	60.7	58.8	65.4	65.8	74.1	61.7	58.1	84.7	749.4	—	0.0	
Replication totals	160.5			179.1			205.3			204.5						

*G = Grand total 749.4.

TABLE 2.—*Analysis of variance of balanced lattice design for nine varieties with recovery of inter-block information.*

Source	D.F.	Sum of squares	Mean square
Replications	3	156.14	—
Varieties (unadjusted)	8	178.05	—
Blocks within replications (adjusted)	8	78.37	9.796
Error (intra-block)	16	81.46	5.091
Total	35	494.02	—

$\frac{1}{5.091} = 0.1964$ and $w' = \frac{3}{4(9.796) - 5.091} = 0.0880$.

Any specific adjusted varietal total with recovery of inter-block information is $V + \frac{\lambda W}{k}$. $\lambda = \frac{w - w'}{kw + w'} = \frac{0.1084}{0.6772} = 0.1601$. Hence, the adjusted total for variety 1 is $85.4 + \frac{0.1601 \times 16.8}{3} = 86.3$, for variety 2 it is $85.1 + \frac{0.1601 \times -8.9}{3} = 84.6$. The calculation of λ can be greatly simplified by working it out algebraically in terms of M and M′ directly as follows: $\lambda = \frac{M' - M}{kM'} = \frac{9.796 - 5.091}{3 \times 9.796} = 0.1601$.
Thus the calculation of w and w′ is not necessary; one may go direct from the analysis of variance to λ in a single step.

The factor (replacing the inverse of the "efficiency factor") by which the error mean square 5.091 must be multiplied to obtain the effective error mean square per plot is $1 + \lambda$ or $1 + 0.1601 = 1.1601$. Hence, the effective error mean square per plot is $1.1601 \times 5.091 = 5.906$ as against 6.659 for the randomized complete block design. The error mean square for ordinary randomized blocks may be readily obtained from Table 2 by subtracting the sums of squares for replications and varieties from the total and dividing the remainder by the appropriate degrees of freedom. The accuracy of the balanced lattice design relative to randomized blocks in this example is, therefore, $\frac{6.659}{5.906} = 1.13$, or 113%. Of this, 3 to 4% might be lost because of inaccuracies in the weights.[4]

[4]The average losses of information for this design due to the inaccuracies in the weights have been calculated by W. G. Cochran. These are as follows:

$\frac{W}{W'}$	1	2	4	6
Per cent loss of information	2.21	3.71	4.46	3.80

W/W′ is the ratio of the true intra-block weight to the true inter-block weight.

Standard error of the mean difference between any two adjusted mean yields per plot is $\sqrt{\frac{2\,(\text{effective error mean square})}{n}}$, where n = number of replications, or $\sqrt{\frac{2(5.906)}{4}} = 1.72$ pounds. The adjusted mean yields can readily be obtained by dividing the adjusted totals by 4, the number of replications.

RELATIVE ACCURACIES OF BALANCED LATTICE DESIGNS WITH 9 VARIETIES AND 4 REPLICATIONS

The estimated relative accuracies of balanced lattice designs in 60 experiments in various counties of the state are shown in Table 3.

TABLE 3.—*Estimated relative accuracies of 60 balanced lattice designs with nine varieties and four replications in percentages, with recovery of inter-block information.*

100	100	102	110	116	133	167	225
100	100	103	110	118	134	173	226
100	100	105	112	119	134	176	227
100	100	106	113	122	134	184	230
100	100	107	113	126	137	193	262
100	100	109	113	129	143	203	264
100	101	110	115	130	151	217	285
				132	153	221	343

Mean relative accuracy 60 experiments = 144.0%.
Median = 118.5%.

Ordinarily, one would not expect much increase in efficiency by using the balanced lattice designs with only nine varieties since the complete block is relatively small. Nevertheless, on 47 of the farms (78%) on which the experiments were conducted, a gain in efficiency was obtained through the use of the incomplete block method. As evident in Table 3, gains ranged from 1 to 243% with 29 out of the 60 experiments showing gains of more than 20%. The mean relative accuracy of all the experiments was 144%. Since, however, the distribution is somewhat skew, the median 118.5% gives a better estimate of the center of the distribution.

The gains are not surprising when one considers the conditions under which the experiments were conducted. The selection of the site for a test was usually left to the county agent and the farmer. Because of the rough topography, uniform areas large enough for even a small test are difficult to find on most farms in West Virginia. Usually, the most convenient areas were selected without much regard to soil heterogeneity. Consequently, many of the complete blocks, although relatively small, were noticeably heterogeneous in soil fertility due to various factors such as variations in soil type, slope, erosion, organic matter, or previous treatments. Under such conditions the designs have made possible a substantial saving of labor in the field for the amount of information obtained.

On the average, four replications of nine varieties in a balanced lattice have proved as efficient as five or six replications with ordinary randomized block designs. The designs are especially useful since with the recovery of inter-block information they can never be substantially less efficient than randomized block designs. Therefore, by designing experiments as balanced lattices little can be lost, but if the soil is very heterogeneous an appreciable amount may be gained in accuracy by a little extra work in calculating.

In ordinary randomized block designs the unadjusted variety means are used as estimates of varietal yields, but in the incomplete block designs the means are adjusted to correct for variations in fertility of the incomplete blocks. In certain of these experiments the rank of varieties was considerably changed by yield adjustments with the incomplete block method. If the soil is very heterogeneous, the adjusted yields should be better estimates of yielding ability of the various varieties than unadjusted values.

BALANCED LATTICE DESIGNS WITH 16 VARIETIES AND FIVE REPLICATIONS

In 1939 and 1940, the balanced lattice design with 16 varieties and five replications was used with certain tobacco and soybean experiments at the Lakin experimental farm. These designs are similar to those with nine varieties except that each complete block contains four incomplete blocks with four varieties each. The efficiency of these experiments is shown in Table 4.

TABLE 4.—*Estimated relative accuracies of balanced lattice designs with 16 varieties and five replications at the Lakin experimental farm in percentages.*

Crop	Relative accuracy
Tobacco, 1940	100
Tobacco, 1939	100
Tobacco, 1940	123
Soybeans, seed	100
Soybeans, hay	146

Two out of the five experiments show gains, one with tobacco shows a gain of 23%, the other with soybeans cut for hay shows a gain of 46%. The average of all five experiments was only 14%. On the whole, soil on the Lakin experimental farm is fairly uniform. In addition, the plots for soybeans (3 by 18 feet) and tobacco (9 by 18 feet) were smaller than those used for corn. Under these conditions one would not expect to find this design very useful, especially since it requires five replications to balance.

5 BY 5 AND 7 BY 7 LATTICE SQUARES

METHOD OF ANALYSIS

The 5 by 5 and 7 by 7 lattice square designs were used in testing strains of corn. The plots were 4 by 5 hills in size with 3½ feet between

hills. Zuber (9) has shown that the more compact incomplete blocks can be made, the more efficient the design will become. In view of this 2 by 10 hill plots would have been better than 4 by 5 hill plots.

The method of analysis of lattice square designs with recovery of inter-block information and the calculations necessary to compare the relative accuracy of these designs with ordinary randomized blocks occupying the same plots and the same replications have been described in detail by Yates (8). The first 7 by 7 lattice square designs used were calculated without recovery of inter-block information, according to the earlier method first presented by Yates (5) and also given by Weiss and Cox (4).

RELATIVE ACCURACIES OF THE 5 BY 5 LATTICE SQUARE DESIGNS

The 5 by 5 lattice square designs with three replications were used in testing corn on the agronomy farm at Morgantown. The gain in efficiency of these designs compared to randomized blocks (exclusive of losses due to errors in weighting which are known to be small) are shown in Table 5 arranged in increasing order.

TABLE 5.—*Estimated relative accuracies of 11 5 by 5 lattice square designs in percentages.*

100	134	139	146	214	240
121	138	143	154	230	

Mean of 11 experiments = 160%.
Median = 143%.

One experiment produced no gain, but the other 10 experiments show a gain of from 21 to 140%. The mean increase in accuracy of all 11 experiments was 60% with a median figure of 43%. These figures show that at Morgantown on the average three replications of the lattice square design were about as efficient as five replications of the randomized block design.

RELATIVE ACCURACIES OF THE 7 BY 7 LATTICE SQUARE DESIGNS

The 7 by 7 lattice squares were used on corn at the Lakin, Kearneysville, and Arthurdale experimental farms. In general, the Lakin farm is fairly uniform in fertility, the Kearneysville farm somewhat less uniform, and the Arthurdale farm quite heterogeneous in fertility. The relative accuracies of the 7 by 7 lattice square designs on these farms is shown in Table 6.

The increases in accuracy at Lakin on the average were somewhat lower than on the other two farms. At Lakin the five, 7 by 7 lattice square designs gave increases in accuracy ranging from 5 to 28% with a mean of 19%.

In 1940, at Kearneysville, the percentage gains ranged from 0 to 75% with a mean gain of 24%. These were calculated according to the earlier method presented by Yates (5) in which the information contained in the incomplete block totals was ignored. According to data presented by Cochran (1), these earlier methods gave about 15% lower gains than the newer methods of analysis. If the 1940

experiments were recalculated according to the newer methods, a greater increase in efficiency might be expected.

TABLE 6.—*Estimated relative accuracies of 7 by 7 lattice square designs on three different state experimental farms in percentages.*

1941, Lakin	1940, Kearneysville*	1941, Kearneysville	1940, 1941, Arthurdale
105	100	93	154*
115	109	166	209
118	113	173	—
127	175	174	—
128	—	—	—
119	124	151	181

*Inter-block information ignored.
Mean of 15 experiments = 137%.
Median = 127%.

In 1941, at Kearneysville with recovery of inter-block information, one of the experiments was 7% less accurate, but the other three were from 66 to 74% more accurate than the randomized block designs. The mean relative increase in accuracy of the four experiments at Kearneysville in 1941 was 51%.

The two experiments at Arthurdale show an average gain of 81% in accuracy. The one conducted in 1940 was calculated without recovery of inter-block information.

DISCUSSION

In general, the balanced incomplete randomized block designs have proved very useful in corn yield trials in West Virginia. In the field they are as easily handled as randomized blocks and, on the average, are substantially more accurate.

Whether a substantial increase can be obtained in an incomplete block design with 9, 16, 25, 49, or more varieties will depend on soil heterogeneity in the area covered by the test. For example, the area used for corn trials on the Lakin experimental farm is fairly uniform. On this farm it is doubtful whether any appreciable gains can be expected with much less than 49 varieties in 2 by 10 hill plots. A 5 by 5 lattice square design with 25 varieties would probably be no more accurate than the same number of varieties in randomized blocks. On the agronomy farm at Morgantown, however, the soil is much more heterogeneous. Here three replications of 25 varieties in lattice squares were, as an average of 11 experiments, as efficient as five replications in randomized blocks. Although they have not been tried, balanced lattice designs with 16 or 9 varieties might even give some increase in accuracy on this farm. That substantial gains can be obtained with as few as nine varieties in balanced lattice has already been pointed out.

Inasmuch as the field work is the same, an incomplete block design would seem highly desirable, especially if one is not well acquainted with the area to be used. Since it can be analyzed both ways, the

decision as to whether it will be worth the extra labor to analyze it according to the full incomplete block method can be made later. If the area turns out to be quite heterogeneous, an appreciable amount might be gained and in any event little information can be lost.

SUMMARY

Data are presented to show the accuracy of 60 corn varietal trials designed as balanced lattices with nine varieties and four replications relative to randomized blocks occupying the same plots and the same replications. The trials were conducted in cooperation with various county agents and farmers throughout the state. Areas for these trials were located by county agents and farmers. Usually areas most convenient were selected without much regard to soil uniformity. Under these conditions the 60 experiments designed and analyzed as balanced lattices showed an average gain of 44% in accuracy over randomized blocks, or four replications in balanced lattice designs on the average were as accurate as five or six replications in ordinary randomized blocks. An example illustrating the method of analysis of a balanced lattice design with recovery of inter-block information is included.

Data showing the relative accuracy of 5 by 5 and 7 by 7 lattice square designs are also presented. The 5 by 5 lattice square designs were used only on the agronomy farm at Morgantown. On this farm as an average of 11 experiments three replications in lattice square design were found to be about as accurate as five replications in randomized blocks.

On the Lakin experimental farm where the soil is more uniform, four replications of the 7 by 7 lattice square designs were, as an average of five experiments, not quite so accurate as five replications of the randomized block designs.

On the state farm at Kearneysville four replications of the 7 by 7 lattice square design proved to be slightly more accurate than five replications of randomized blocks based on an average of eight experiments, four of which were calculated without recovery of inter-block information.

At Arthurdale as an average of two experiments, four replications in 7 by 7 lattice square design were as accurate as seven replications in randomized blocks.

On the whole, the increase in accuracy of 7 by 7 lattice square designs over randomized blocks represented a saving of about one replication in four.

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ATMOSPHERIC DROUGHT TESTS OF SOME PASTURE AND TURF GRASSES[1]

J. C. CARROLL[2]

WHERE hot, dry winds blow frequently during the growing season, many plants die even though soil moisture has not been reduced to the wilting point. Such desiccation of plants is called atmospheric drought and has not received as much attention as soil, or edaphic drought. Although atmospheric drought seldom affects growth and duration of grasses in the Great Lakes region, these data on atmospheric drought are submitted in the hope that they will be of interest to those concerned with the physiology and ecology of grasses.

Schultz and Hayes (4)[3] in a study of atmospheric drought resistance of a number of pasture grasses and legumes by means of the artificial drought machine devised by Shirley (5) obtained results which agreed closely with field observations.

Aamodt and Johnston (1) tested the effects of atmospheric drought on a number of spring wheat varieties. They found that the plants could be hardened to atmospheric drought by short exposures to either soil drought or atmospheric drought.

Vassiliev (6) deems it possible to breed plants resistant to atmospheric drought but not to soil drought.

MATERIALS AND METHODS

Grasses included in this test were Kentucky bluegrass (*Poa pratensis* L.), wood meadow grass (*P. nemoralis* L.), Astoria bent (*Agrostis tenuis* L.), cocoos bent (*A. tenuis* L.), South German mixed bent (*A. tenuis* L., *A. palustris* L., and *A. canina* L.), highland bent (*A. canina* L.), Chewings fescue (*F. estuca rubra fallax* L.), red fescue (*F. rubra*), sweet vernal (*Anthoxanthum odoratum* L.), red top (*A. alba* L.), carpet grass (*Axonopus compressus* L.), and Bermuda grass (*Cynodon dactylon* L.). With the exception of Bermuda and carpet grass, all species were seeded in the fall of 1939 and had established a thick, heavy sod within a year. Bermuda and carpet grass were sown in the spring of 1941, and although good stands were secured, they did not produce as heavy sod as did the other species.

One-half of each plot of the earlier seeded species was fertilized with ammonium sulfate at the rate of 5 pounds per 1,000 square feet in April, July, and October each year. The unfertilized and fertilized portions of the plots were designated as "low- and high-nitrogen sections", respectively. Bermuda and carpet grass remained unfertilized.

The plots were located on Wooster silt loam which was in a high state of productivity.

Samples were taken the middle of September 1941. A golf cup-hole cutter was used to lift plugs of sod 4¼ inches in diameter and approximately 3 inches thick

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[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication September 4, 1942.

[2]Assistant Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 79.

from each plot. These samples were placed in glazed earthenware jars of the same dimensions.

Half the samples of each treatment were hardened by exposure to atmospheric drought conditions for 3 successive days for a period of 5 hours daily in a draft oven where the temperature was maintained at 35° to 37° C and the relative humidity at approximately 20%. The wind velocity was between 3 and 4 miles per hour. The low humidity was achieved by connecting the air intake and outlet to a closed container filled with anhydrous calcium sulfate. At the end of the daily hardening period, the samples were removed to a greenhouse bench. They received no water during this period. The remaining samples were exposed to atmospheric drought without being hardened.

Both series of samples were exposed to atmospheric drought for periods of 12, 18, and 24 hours under the same conditions of temperature, humidity, and wind movement at which half of the samples were hardened. At the end of each exposure, the samples were placed in the greenhouse and watered periodically.

Percentage of survival was estimated at the end of 3 weeks. In estimating percentage of survival, each separate stem was considered a plant. In preliminary tests, estimations of survival were in close agreement with actual counts.

RESULTS

Since the injury to samples exposed for 12 hours was very slight, those results are not reported.

Differences among most species in ability to survive atmospheric drought were marked (Table 1). As might be expected, the two southern species, carpet grass and Bermuda grass, excelled the other species tested in resistance to atmospheric drought. In the 18-hour

TABLE 1.—*Comparative survival of certain species of turf grasses exposed to atmospheric drought.*

Grass	18-hour exposure*				24-hour exposure†			
	Hardened		Unhardened		Hardened		Unhardened	
	Low N	High N	Low N	High N	Low N	High N	Low N	High N
Carpet grass	100	—‡	90	—‡	95	—‡	90	—‡
Bermuda grass	100	—‡	90	—‡	95	—‡	90	—‡
Kentucky bluegrass	90	80	75	60	80	60	60	40
Cocoos bent	90	75	70	60	80	60	70	40
Red top	80	75	60	45	70	50	70	35
Wood meadow grass	70	50	50	30	65	40	35	10
Astoria bent	85	75	70	40	60	30	45	15
Highland bent	85	70	60	45	65	55	35	20
Chewings fescue	90	70	70	30	50	25	40	10
Red fescue	90	65	70	25	50	25	35	15
Sweet vernal	60	45	20	10	40	15	25	5
South German mixed bent	65	45	40	25	30	20	25	10

*Average of two replications.
†Average of four replications.
‡These sections remained unfertilized.

exposure only a few of the species from the low-nitrogen series which had been hardened showed more than 20% injury, but the majority of the species which were unhardened suffered injury up to 80%. Grass from the high-nitrogen section, although capable of hardening to some extent, suffered greater injury than grass from the low-nitrogen section. Grass on the high-nitrogen section had a more lush growth than that on the low-nitrogen section and greater injury was expected, since previous work (2, 3) on cold, drought, and heat resistance of turf grasses had shown that under such conditions, grass was less hardy than where growth was less rapid.

Injury from 24-hour exposure was greater than from 18-hour exposure to all species except carpet and Bermuda grass which were very little affected.

Of the grasses most commonly used in turf mixtures in the northern states, the fescues showed the least resistance to atmospheric drought. Kentucky bluegrass, cocoos bent, and red top were most resistant.

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NOTE

CONTROL OF APHIDS ON SUGAR BEETS UNDER GREENHOUSE CONDITIONS

THE control measure here described was adopted after numerous trials of several others, such as weekly sprayings and fumigations with various nicotine sprays, nicotine powders, cyanide gas, and trials of chloropicrin.

The greenhouse was relatively new, in good repair, and tight. It contained 18,750 cubic feet of space. The temperature in the house ranged from 65° to 75° F and the relative humidity from 55 to 65%.

The following fumigation program proved to be satisfactory and completely eliminated aphids from sugar beets in the greenhouse without injury to the plants: Weekly fumigations were made using 180 cc of a 40% nicotine compound, or approximately 1 cc per 100 cubic feet of greenhouse space. Sixty cc of the liquid were placed in each of three shallow containers on 110-volt, 600-watt electric hot plates distributed along the center walk throughout the length of the greenhouse. The hot plates were connected to a circuit operated by an electric time clock which was set to turn on the current in the evening after sundown and heat was applied for 1 hour and 15 minutes. This was sufficient heat to vaporize all of the liquid completely. The house was tightly closed for the night and thoroughly aired out the following morning.

This procedure proved to be convenient and effective. Some 40% nicotine compounds leave considerable residue in the containers, whereas others evaporate almost completely; but all seem equally effective. Other types of heating devices may be used satisfactorily.—F. F. LYNES AND R. J. LITTLER, *Beet Seed Breeding Department, Holly Sugar Corporation, Sheridan, Wyoming.*

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WINTER COVER CROP SEEDS

Winter cover crops, including Austrian winter peas, the vetches, crimson clover, lupines, and rye grass, are important in maintaining and improving total agricultural production. Most of this seed is produced generally in the states of the Pacific Northwest and used extensively in the southeastern states to provide nitrogen, organic matter, and soil protection. With decreased supplies of nitrogen for commercial fertilizer, greater importance is being placed upon the use of winter legumes in maintaining productivity in the southeastern states.

The carryover supplies of these seeds at the beginning of the 1942 season were somewhat larger than a year ago, the total of all winter cover crop seeds being about 20,000,000 pounds. The 1942 production amounted to about 250,000,000 pounds, which was considerably larger than was anticipated in the 1942 goals. The largest increase was in Austrian winter peas, the total production being approximately 132,000,000 pounds, which was more than twice the established goal of 61,300,000 pounds. This production is the result of a much larger than average yield and a marked increase in the acreage. The yield was 961 pounds as compared with a 5-year average of 773 pounds and the acreage 137,000 compared with a 1941 acreage of 56,500. The estimated production of 31,600,000 pounds of hairy vetch seed is considerably less than the established goal of 47,200,000 pounds. The average yield of hairy vetch for 1942 is estimated at 225 pounds compared with the 5-year average yield of 253 pounds.

Legumes that promote soil fertility may actually help feed and clothe the fighting men upon whom victory directly depends. Men too need nitrogen. Perhaps even the gun crews firing 16-inch guns in the future may be fed and clothed from crops fertilized with the help of the legumes that farmers are planting this fall. High explosives and winter legumes—comrades in a common cause.

A larger acreage of crop land is used for forage purposes than for any other one crop except corn. The hay and pasture crop production goal for 1942 was 71½ million acres. In addition several million acres of rotation pasture were grown with hay crop seed which helped to furnish the forage supply to produce livestock. The war emergency requires a marked increase in the production of livestock and livestock products. Forage crops are an important part of the rations for all kinds of livestock and the maintenance of a sufficient acreage to supply roughage is essential in the achievement of the production goals for meat and dairy products and wool. Unless seed supplies are available it will not be possible to maintain the hay and rotation pasture acreages of these biennial and perennial crops.

PRODUCTION IN 1942

The 1942 production of certain grass and legume seeds is still not sufficient to meet the seeding requirements for 1943. The present

preliminary estimates[3] indicate that it will be considerably less than the established goals, about 60% for alfalfa, 50% for red clover, 61% for alsike clover, 70% for sweet clover, and 92% for lespedeza. The total 1942 production of alfalfa, red, alsike, and sweet clover is only about 86% of the 1941 crop. Similar data are not available for many of the grasses, particularly those common to the Southern Great Plains.

This low production can be attributed principally to competition of other crops. Definite assurance of the price of competing crops is given, but no assured price for grass and legume crop seeds. Also, much of the acreage was used as forage for increased livestock and insufficient was left for seed production. For the immediate purpose, utilization of all the forage required by livestock might seem the wise procedure, but unless the seeds are produced to revegetate and maintain the forage crop acreage, decreased supplies of forage for livestock will result. The desirable requirements of forage crop seeds for 1943 will be fully as great as in recent years and considerably larger than the available supplies.

PRODUCTION PROBLEMS IN 1943

A serious shortage of farm labor exists, yet the war demands greater production of food crops and livestock products in 1943. To maintain and increase production per acre and to conserve labor, greater use must be made of legume and grass crops. Weather which directly influences seed production is not subject to control, whereas other factors, such as price, labor, and material required, can be regulated, at least to the extent of facilitating production. The need for increased production of legumes and grasses in 1942 was pointed out to farmers and seed dealers, but the response was not satisfactory.

Labor shortages resulting from military requirement and industrial competition, the limitations on fertilizers, and the competition of other crops indicate that the 1943 production of hay crop seeds may be considerably less than in 1942. In the case of native grasses harvested by strippers and combines, there is danger that operators will not be able to get sufficient tires and gasoline to move their equipment over the long distances necessary to reach locations where seed is available.

The scant supplies of the native grass seeds, as buffalo grass and the gramas, available for establishing turf on airfields and other military areas also present a problem. Since 1935 many of the native grasses of the Great Plains have been used in conservation plantings on arable range lands. Previously most of these species had never been used extensively and the collection and processing of seed, as well as the development of correct agronomic technics in their establishment, presented new problems for study and research.

The failure to attain requirements of grass and legume seeds is due primarily to the competition of other crops for which guaranteed prices are offered either directly or indirectly. In the case of cover

[3]By the Agricultural Marketing Service, U.S.D.A.

crop seeds (winter peas, vetch, crimson clover, lupines, and rye grass) for which minimum prices have been guaranteed, production on the whole was markedly increased.

The low 1942 production of the principal grass and legume seeds clearly indicates the need for immediate action to develop a program that will prevent price exploitation and to encourage seed production in 1943 of those legumes and grasses that are necessary in our war effort. Such a program is necessary to insure adequate production of feeds and foods vital for the war and for the rehabilitation of scorched earth areas and other areas of conquered countries now being exploited by the Axis. You may remember Carl Sandburg's line of verse, "I am the grass; I cover all". After suggesting the battle havoc of Austerlitz and Waterloo, Gettysburg, Ypres, and Verdun, Sandburg wrote:

> "Two years, ten years, and passengers ask the conductor:
>
> What place is this?
> Where are we now?
>
> I am the grass.
> Let me work".

PRODUCTION OF VEGETABLE SEEDS

Production of vegetable seeds in 1942 as a whole was considerably more encouraging than the production of 1941. No surveys have been made since 1942 plantings were completed to determine the production for 1942, but from present observations it appears that it will exceed that for 1941 on all items except lettuce, and on most items will be much above 1941. However, the production in many cases has not appeared to reach either the prospective production as estimated in March, or the goals set up for 1942. This is true of all dwarf beans, garden beets, cabbage, carrots, kale, leek, onion, and turnip. Beet, carrot, and onion appear to be at least one-third below the production expected in the spring. Production of pole beans, mangel beet, Swiss chard, both smooth and wrinkled peas, radish, summer squash, and tomato appear to have exceeded the goals for 1942.

DWARF ESSEX RAPE

Before 1941 the farmers of the United States produced relatively little seed of the Dwarf Essex rape, because they were unable to compete successfully with prices of foreign seed. The domestic production was less than 1,000,000 pounds in 1940. Mainly because of better prices this was increased to 4,500,000 pounds in 1941. The production for 1942 is estimated at 6,000,000 to 7,000,000 pounds which would not be sufficient to meet normal domestic needs and lend-lease requirements. Whether the much higher price will result in decreased use of seed for farm seedings or whether, in spite of the higher price, there will be an increased demand for seed to provide pasture and forage to meet the production goals of meat and dairy products, remains to be seen.

Practically all of this seed has been produced in Oregon, Washington, and Idaho where average yields in different districts varied from 700 to 1,800 pounds per acre. This production is largely attributable to a price per pound that will insure a return commensurate with that obtained from competing crops.

During the past year considerable seed of the annual bird rape generally grown for oil was imported from Argentina. Because of the limited supply and high price of seed of Dwarf Essex rape many farmers sowed the Argentine seed with the intention of using it for forage, but later found that it was a bad weed and not palatable to livestock.

SUGAR BEETS

G. H. Coons of the Division of Sugar Plant Investigations has recently described how the seed bottleneck curtailed the production of beet sugar during World War I and how this was eliminated by an accomplishment in scientific agriculture. His statement follows:

"The American beet sugar industry by capitalizing on the research of the decade 1921–1931 and by breaking the tradition of depending upon European breeding establishments for sugar-beet seed has achieved complete independence of Europe for this vital essential. From the position of importing nearly all its requirements of sugar-beet seed, the industry in the last few years has moved to the position of producing all the seed it needs, with some to spare to our allies and to friendly nations. More than mere production of sugar-beet seed has been involved because, at the same time, the industry has supplied itself with better adapted varieties than ever were imported and has done this within the price ranges formerly paid. The development has therefore been not only economical but highly advantageous. The new, American-grown varieties have given sugar beet growers more crop security than ever before.

"To appraise the job involved in achieving independence of European sugar-beet seed supplies, not only the total annual seed requirement for the American sugar-beet crop needs to be known but the breakdown of the total into the kinds of seed used in the respective factory districts must also be considered. To plant the 1,061,000 acres reported for 1942, taking 15 pounds per acre as the average planting rate, required nearly 16,000,000 pounds of seed. In itself, the production of seed in such quantity represents a large undertaking. But no single sugar-beet variety, or type, meets the complex needs of our sugar beet industry. Curly-top-resistant varieties have not shown themselves suited for non-curly top conditions, largely because they are susceptible to leaf spot. On the other hand, leaf-spot-resistant types, because they are not curly-top resistant, would give disastrous results in the western districts subject to curly top. Hence, the total requirement for seed must be analyzed with respect to the respective types and varieties needed for the various districts served.

"The sugar-beet-seed enterprise, therefore, in making its contribution to American Agriculture has done two things. It has, in war time, prevented seed shortage from limiting production of vital

sugar-beet crops. Furthermore, it has been the agency whereby varieties improved in productiveness because of greater disease resistance or better adaptation have promptly been made available to sugar-beet growers''.

CONCLUSION

I have given just a few examples of how the seed supply affects the food production in the war. Many other equally important and fascinating stories could be told about other crops. It will suffice for the present to conclude with a statement prepared by R. A. Oakley on the seed situation in World War I that is equally applicable to the situation we now face. He said, ''Never before in the history of our country has the question of seed supply been so vitally important, and never has it been so necessary that all legitimate agencies engaged directly or indirectly in the production or dissemination of seed be utilized efficiently for the national good.

''Temporary seed shortages have developed under new economic conditions, and they may continue, but farmers and seedsmen are resourceful, and they may be expected to find ways and means to meet not only the needs of this country, but also those of other countries which may be dependent upon us''.

THE FERTILIZER SITUATION AND THE WAR[1]

F. W. PARKER[2]

MORE than 2,300,000 farmers use a total of approximately 9,000,000 tons of commercial fertilizer costing them some $300,000,000. An industry of such magnitude, deriving its raw materials from widely scattered sources, obviously would be affected by the war program of the nation. It is our purpose to consider the effect of the war on fertilizer supplies and practice for the 1942–43 season.

DEMAND FOR COMMERCIAL PLANT-FOOD

There may be a shortage of fertilizers in the spring of 1943. Two elements, namely, demand and supply, operate to produce a shortage. First consideration will be given to the influence of the war on the demand for fertilizers.

Under the stimulus of war, farm production and farm prices have increased so that the total farm cash income has increased from an average of $8,648,600,000 for the period 1936–40 to $11,830,000,000 in 1941 and an estimated $15,600,000,000 in 1942. This 80% increase in farm cash income will certainly cause a great increase in the demand for fertilizers.

In the 5-year period referred to, 2.53% of the previous year's farm cash income was spent for fertilizer. If the same percentage of the 1942 income is spent for fertilizer in 1943, fertilizer sales would approximate 11,740,000 tons, an increase of 4,135,600 tons over the the average tonnage for 1936–40. This potential demand and the relationship between farm income and fertilizer consumption is shown in Fig. 1. The figure indicates that the demand in 1942 was about 750,000 tons greater than the supply. In 1943 the indicated demand may exceed the expected supply by almost 3,000,000 tons.

On the foregoing basis, and including Hawaii and Puerto Rico, it may be estimated that in 1943 there will be a market for 665,000 tons of nitrogen, 1,100,000 tons of phosphoric acid, and 655,000 tons of potash for fertilizers.

In time of war the demand for a commodity may greatly exceed the quantity required to achieve national objectives. This is the case with respect to fertilizers. Table 1 gives the calculated consumption of nitrogen by various crops in 1941 and the amount of fertilizer nitrogen required to meet the national crop production goals in 1943. The latter figure is based on the same average rate of fertilization and the same average yields as in 1941. It does not reflect changes in nitrogen fertilization which will result from recent governmental action. These data indicate a nitrogen requirement of 462,000 tons, some 203,000 tons less than might be expected to result from the great increase in farm cash income.

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[1]Presented at the annual meeting of the American Society of Agronomy at St. Louis, Mo., November 12, 1942.

[2]Division of Soil and Fertilizer Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture.

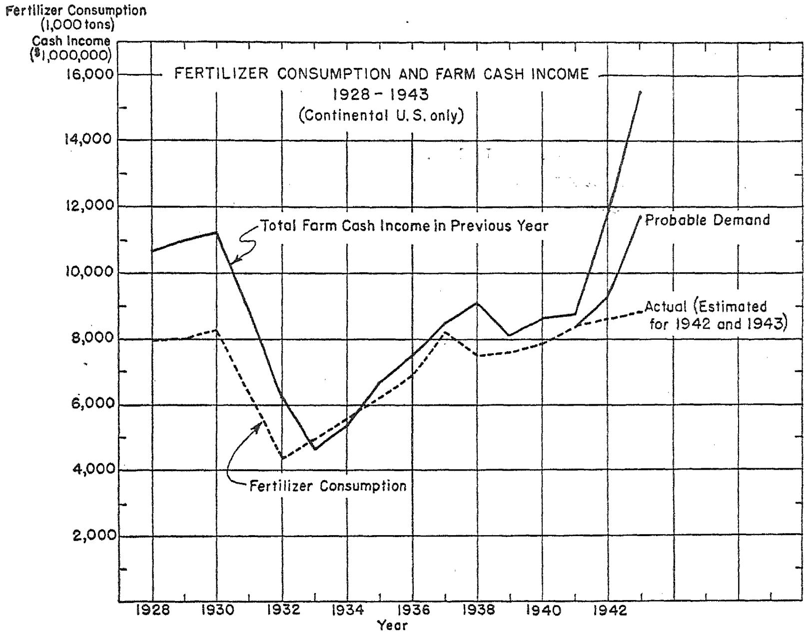

FIG. 1.—Fertilizer consumption and farm cash income, 1928–1943. (Continental U. S. only.)

TABLE 1.—*Nitrogen consumption by crops in 1941 and unadjusted requirements for 1943 in tons of nitrogen.*

Crop	Used in 1941	Requirements in 1943*
Cotton	85,755	90,665
Corn	88,636	91,594
Potatoes	34,384	36,570
Oats and barley	15,152	16,250
Tobacco	21,112	23,606
Vegetables	63,246	66,679
Fruit and nuts	51,112	51,112
Wheat	18,649	14,689
Sugar cane and beets	7,178	8,044
Forage crops	8,225	8,225
All other crops	27,433	18,702
Total for continental U. S.	420,881	426,136
Hawaii and Puerto Rico	35,281	36,000
Total U. S.	456,162	462,136

*Based on 1941 average rates of fertilization.

The 1942–43 requirements for phosphoric acid and potash have been estimated at 1,100,000 tons P_2O_5 and 512,000 tons K_2O. These estimates, unlike the estimate of nitrogen requirements, are based

on the new grades established for 1942–43 and on increased use of phosphates and potash for legumes. They also include the tonnage to be distributed by the Agricultural Adjustment Administration.

THE SUPPLY OF COMMERCIAL PLANT-FOOD

The outbreak of war in 1939 immediately began to influence the source and quantity of our supplies of fertilizer materials. Fortunately, because of the development of the domestic nitrogen, phosphate, and potash industries, this war had less effect on our fertilizer supplies than the first world war.

The effect of the war on our nitrogen supply is shown by the data in Table 2. The war stopped substantial imports from Europe, increased imports from Chile, reduced our exports of fertilizer nitrogen, increased domestic production of by-product ammonium sulfate, and diverted nearly all domestic synthetic ammonia products from fertilizer to war purposes. The net effect of all of these changes is to give, with normal use of natural organics, an expected supply of 408,000 tons of nitrogen for 1942–43. This compares with consumption of 390,002 tons in 1939 and 456,908 tons in 1941. In only 3 years, 1937, 1941, and 1942, has consumption exceeded 400,000 tons.

TABLE 2.—*Fertilizer nitrogen supplies for U. S. consumption in short tons of nitrogen.*

Material	1939	1941	1942–43*
Ammonium sulfate	118,650	138,248	160,000
Sodium nitrate	120,731	146,300	172,000
All ammonia liquors	47,500	65,200	5,000
Cyanamid	20,811	25,700	9,000
Uramon, calurea, etc.	7,526	20,000	5,000
Ammonium phosphates	6,079	6,200	5,000
All other chemicals	20,410	3,850	2,000
Natural organics	48,295	51,410	50,000
Total	390,002	456,908	408,000

*Since this estimate was prepared, the nitrogen situation has materially improved. As of January 1943, it appears that the supply may be 5 to 10% greater than these figures indicate.

The data on nitrogen supplies include items on which considerable uncertainty exists due to factors connected with the war. The supply of Chilean nitrate of soda may be smaller or larger than the indicated tonnage. The production of synthetic ammonia liquors and Uramon has recently been resumed on a limited scale. There will be 10,000 tons or more of nitrogen from these sources. This represents a small but distinct improvement in the nitrogen situation.

The indicated supply of fertilizer nitrogen is 54,000 tons less than the requirement estimate given in Table 1. It is some 257,000 tons lower than the calculated potential demand based on farm cash income. The adjustment of supply to requirements in the face of the great demand for nitrogen constitutes one of the major problems of fertilizer distribution.

The supply situation as regards superphosphate is summarized

in Table 3. These data show that there will be an abundant supply of phosphoric acid. This will be achieved without capacity production by the industry as it has a rated capacity of 1,712,000 tons P_2O_5. The available supply of double-superphosphate will probably be somewhat reduced due to exports to other United Nations.

TABLE 3.—*United States supply of phosphoric acid for fertilizers in short tons of* P_2O_5.

Material	1939	1941	1942–43
Commercial distribution:			
Superphosphate	566,000	650,000	780,000
Double superphosphate	61,000	66,000	60,000
Other phosphates	51,000	50,000	38,000
Total	678,000	766,000	868,000
Government distribution:			
Superphosphate	0	146,000	240,000
Double superphosphate	77,000	45,000	0
Other phosphates	0	6,000	0
Total	77,000	197,000	240,000
Grand total	755,000	963,000	1,108,000

Transportation problems, particularly the rail movement of rock phosphate and sulfur, are the factors that might limit the indicated production of phosphoric acid.

The potash supply situation, Table 4, is similar to the phosphate case in that there is no shortage. The war has stopped all potash imports. Domestic consumption has increased from 405,000 tons K_2O in 1939 to 458,000 tons in 1941, while the 1942–43 supply for fertilizer purposes is estimated at 560,000 tons. This assumes plant operation at 95% over-all efficiency. The supply may be reduced somewhat by

TABLE 4.—*United States supply of potash for fertilizers in short tons of* K_2O.

Material	1939	1941	1942–43
Muriate of potash:			
Domestic	273,508	374,783	460,000
Imported	110,040	8,300	0
Manure salts and kainit:			
Domestic	8,039	28,626	40,000
Imported	3,223	0	0
Sulfates of potash:			
Domestic	146	32,531	45,000
Imported	30,060	0	0
Miscellaneous*	20,000	13,760	15,000
Total	405,000	458,000	560,000

*Vegetables potash, natural organics, nitrate of soda-potash, etc.

increased exports to some of the United Nations. In any case it appears we will have enough potash to meet our requirements but not enough to meet all possible demands.

The favorable potash situation is due, of course, to the rapid development and expansion of our domestic industry. We now have ample domestic supplies of all potash salts, potassium nitrate excepted, for our normal fertilizer and chemical requirements.

The plant-food demand, requirement, and supply situation as developed to this point is shown in Table 5. Only in the case of nitrogen is there a real shortage when compared to requirements. There the shortage amounts to about 12%. The situation, of course, is complicated by the fact the demand is much greater than the indicated requirements.

TABLE 5.—*Summary of estimated demand, requirements, and supply of plant-food for 1942–43 in short tons.*

	N	P_2O_5	K_2O
Demand	665,000	1,100,000	655,000
Requirement	462,000	1,100,000	512,000
Supply	408,000	1,108,000	560,000
Consumption, 1941	457,000	963,000	458,000

THE FERTILIZER DISTRIBUTION PROBLEM

Long before Pearl Harbor the U. S. Dept. of Agriculture was following the fertilizer supply and demand situation. When it became apparent that there would probably be a considerable shortage of nitrogen but rather ample supplies of phosphoric acid and potash, the war agencies and the U. S. Dept. of Agriculture established the following general principles for developing an equitable plan of fertilizer distribution:

1. Crops most essential to the war effort should have first call on our fertilizer nitrogen supplies.
2. Chemical nitrogen should not be used on nonessential crops, on essential crops of which there was a very large surplus in storage, or under conditions where it gives a low return.
3. The consumption of phosphoric acid and potash should be increased to utilize most of our productive capacity and to offset partially the lower yield that would result from reduced nitrogen fertilization.
4. With the limitations indicated, nitrogen should be distributed on a historical basis.

Following Pearl Harbor, a Technical Committee on Fertilizers, under the chairmanship of Dr. R. M. Salter and later Mr. W. F. Watkins, with the assistance of the Land-Grant Colleges and the National Fertilizer Association, assembled a large amount of data relating to fertilizers. At the same time the Industry Advisory Committee was studying the problem of fertilizer distribution. Both studies indicated the advisability of standardizing fertilizer grades as an important step in any distribution program.

The War Production Board and the Office of Price Administration worked with the U. S. Dept. of Agriculture in a fertilizer grade standardization program. The National Fertilizer Association rendered valuable assistance in many ways. The objectives of the program were:

1. To reduce the number of grades sold in each state to the minimum number required for efficient fertilization of the state's crops.
2. To secure greater uniformity of grades within regions.
3. To adjust the plant-food ratio in grades so that nitrogen consumption in mixed fertilizers would be reduced about 20%, but the consumption of phosphoric acid and potash would be increased.
4. To increase the plant-food content of fertilizers in those regions using a large tonnage of low analysis grades.

A word of explanation about the change in plant-food ratios is probably needed as there has been some criticism on this point. The ratio had to be changed in order to reduce nitrogen consumption without reducing the use of phosphoric acid and potash. Furthermore, widening the ratio tends to increase the efficiency with which the nitrogen is utilized. Admittedly the phosphoric acid and potash may not be efficiently utilized in some instances, but in general their increased use should help offset the decrease in yield expected from the smaller application of nitrogen.

In adjusting the ratio of nitrogen to phosphoric acid and potash, the ratio was widened most in those regions in which the response to phosphoric acid and potash was relatively great as compared to response to nitrogen. The least change in ratio was made in the regions in which the need for nitrogen was relatively great. Considering the country as a whole, the N-P_2O_5 ratio in 1942–43 will be similar to the ratio for 1927.

The selection of grades for each state, within the limitations imposed by the national objectives, was left to the agronomists of the several states. They cooperated fully and effectively in a series of seven regional grade conferences. The fertilizer industry as well as the agronomists then participated in a second series of conferences in which a few changes were made in the grades recommended by the agronomy conferences. Other minor changes were made before the new grades were made official by the issuance of Conservation Order No. M-231 by the War Production Board on September 12.

It is too early properly to evaluate the results of the grade standardization program. The number of grades sold in the United States will be reduced from about 900 to 90. The grades per state will be reduced from an average of 88 to 16. This is a pretty good record, but it now seems that the reduction in grades should have been more drastic in some states. Substantial progress has been made in securing grade uniformity within regions although there is room for further improvement in this respect.

Two other steps taken to conserve nitrogen are detailed in W. P. B. Conservation Order No. M-231. They are (1) no chemical nitrogen

in 1942 for fall-sown small grains to be harvested for grain, and (2) no chemical nitrogen for nonessential uses such as lawns, golf courses, and parks. It is probable that the use of chemical nitrogen will be further restricted on corn in the commercial corn area, on all small grains in areas where there is little response to nitrogen, and on certain minor crops. It is estimated that these conservation measures will result in a saving of from 40,000 to 50,000 tons of nitrogen, thereby reducing our requirements to 400,000 or 410,000 tons. Further reduction in nitrogen consumption should not be necessary.

A discussion of the nitrogen fertilizer situation would not be complete without reference to the use of oil-seed meals. The supply of oil-seed meals for domestic consumption has increased from a 1935–40 average of about 4,000,000 tons to an estimated 8,225,000 tons in 1942. Much of this increase can be used for feed, but very substantial quantities should be used in fertilizers. Normal consumption of oil-seed meals in commercial fertilizers is about 60,000 tons. The U. S. Dept. of Agriculture has recommended that an additional 500,000 tons be so used. The Office of Price Administration has recently indicated that fertilizer price ceilings will be adjusted to make possible the increased utilization of oil-seed meals. The fertilizer nitrogen supply may, therefore, be increased some 30,000 tons making a total of 438,000 tons as compared to an adjusted requirement of 410,000 tons of nitrogen. It is also probable that the use of cottonseed meal for fertilizer on southern farms will increase substantially this year. Such an increase is desirable, should be encouraged, and will return a good profit to the farmer.

Following the establishment of the new grades the U. S. Dept. of Agriculture and W. P. B. worked out a schedule, for each state, showing which of the new grades are to be substituted for the grades formerly sold in the state. It is expected that the indicated substitution of grades will result in the manufacture and sale of a tonnage of mixed fertilizers approximately equivalent to the 1940–41 tonnage. Having effected such a saving of nitrogen in mixed fertilizers, the tonnage of nitrogen materials available for direct use should be about the same as in 1940–41. If these conditions prevail, the equitable distribution of fertilizers should not be too difficult.

At the request of the War Production Board, the Fertilizer Industry Advisory Committee has suggested a plan for the distribution of mixed fertilizers and nitrogen materials to farmers. It is probable that the plan, after some modification, will be used in 1943. The industry has recognized the necessity and is willing to assume the responsibility for, "A program and plan for the equitable distribution of the available supply to all buyers in a manner that will be fair to each and every user of fertilizer engaged in the production of agricultural commodities necessary to the war effort". The plan of the committee requires each purchaser of fertilizer to fill out a statement indicating, "The quantities and grade of fertilizer purchased in 1941–42 and the quantity and grade desired for 1942–43 and the crops on which they are to be used". It is expected that W. P. B. will employ field agents to act as liaison men between farmers, dealers, and fertilizer manufacturers. Finally, it is suggested

that County War Boards be designated to serve as appeal or mediation boards to handle complaints regarding fertilizer distribution.

The fertilizer industry is to be commended for the way in which it has worked with various governmental agencies on fertilizer problems. It has assumed a real task in accepting the responsibility for the equitable distribution of fertilizers in 1943. It is expected to measure up to the task and opportunity.

A FORWARD LOOK

This discussion would not be complete unless some consideration was given to fertilizer problems that may confront us during the balance of the war years and in the post-war period.

Predictions regarding nitrogen supplies for agriculture for 1943–44 are not in order. Too much depends on the course of the war. We should be prepared to cope with a shortage as great or even greater than we face for 1942–43. Agronomists in every state should follow as closely as possible fertilizer usage this year and be prepared to recommend such changes as may be necessary to meet plant-food shortages, and secure more efficient utilization of available fertilizer supplies.

It is probable that some revision of fertilizer grades will be needed before another season. If so, state agronomists, within the limits imposed by national objectives, will be expected to select the grades. More uniformity within regions is desirable and several states should further reduce the number of grades to be offered for sale.

Some changes produced by war should be retained in the post-war period. Fertilizer grade limitation is one of those changes. Steps should be taken in many states to include a provision in the fertilizer control law or regulations that will make possible a reasonable limitation of grades of fertilizer to be offered for sale. Where such provisions are in effect, fertilizer grade selection is usually made by the agricultural college and the state fertilizer control officers in consultation with representatives of the fertilizer industry.

The advent of war has shown how essential it is to have dependable statistics on plant-food consumption. State fertilizer grade tonnage reports are one of the most valuable sources for such data. Such reports, however are not available for Delaware, Georgia, New Hampshire, Oregon, Tennessee, Virginia, and Washington. Agronomists and the fertilizer control officials of those states would render their state and the nation a useful service if arrangements were made to secure such reports for 1942 and subsequent years.

The post-war period will present agronomists with the reverse of our war nitrogen problem. Under the impetus of war the country's capacity for producing synthetic ammonia is being vastly increased. Our total capacity will be more than twice as great as our maximum pre-war consumption of nitrogen for all purposes. There will be synthetic ammonia plants in ten or more states. It is expected that the farm price of nitrogen will be substantially lower than in recent years. The problem of the utilization of this nitrogen is to be studied by a National Joint Committee on Nitrogen Utilization. Members

of this Society will have an important place in the work of that committee.

Similar, but less acute, problems may face us with respect to the utilization of increased supplies of phosphoric acid and potash. Agronomists should lead in their effective utilization. The demands for research and leadership in the post-war years may well be as great or greater than in the war period.

THE INHERITANCE OF BRITTLE RACHIS IN BARLEY[1]

I. J. JOHNSON AND EWERT ÅBERG[2]

THE occurrence of brittle rachis in barley, characteristic of *Hordeum spontaneum* C. Koch and *H. agriocrithon* E. Åberg (1)[3] has been observed and studied by several investigators. In 1889, Liebscher (4) obtained brittle rachis plants from a cross of *H. distichum* L. and *H. vulgare* L. and in 1907 Biffen (3) reported a 3:1 ratio for brittle and normal rachis in crosses between *H. spontaneum* and two varieties of *H. vulgare*.

Brittle rachis plants were obtained in the F_1 generation by Ubisch (7) in crosses between nonbrittle cultivated varieties. A ratio of 9 brittle to 7 normal in the F_2 was in agreement with a complimentary factor interaction with two dominant factor pairs necessary for the expression of the brittle rachis character. Ubisch assumed that both of the dominant genes for brittle rachis were present in *H. spontaneum*.

Schiemann (6) found that the degree of brittleness of the rachis was influenced by an inhibitor, and that plants heterozygous for the two dominant brittle genes were nonbrittle in the presence of the dominant inhibitor gene. The inhibitor was assumed to be absent in *H. spontaneum* but present in cultivated varieties. A third factor for brittle rachis was found in a six-rowed hulless barley, but its effect was less pronounced than from the two dominant genes in *H. spontaneum*.

Previous studies have not been reported on the occurrence of brittle rachis from crosses between varieties of barley now grown in the United States or on the inheritance of brittle rachis in crosses with *H. agriocrithon*.

MATERIALS AND METHODS

In 1941, among several crosses used in the barley breeding program at the Iowa Agricultural Experiment Station, the combination Peatland × C.I. 4821 produced all brittle rachis plants in the F_1 generation. Peatland, a six-rowed, white, rough-awned, short-haired rachilla variety, was developed by selection at the Minnesota Experiment Station and is rather extensively used in breeding studies. The variety C.I. 4821, a six-rowed, black, rough-awned, long-haired rachilla barley, is an introduction from Manchuria and was obtained from the Office of Cereal Crops and Diseases, U. S. Dept. of Agriculture, as parental material in breeding for resistance to leaf rust. *H. agriocrithon* variety *eu-agriocrithon* described by Åberg (1) was originally obtained from Tibet. This variety is a six-rowed, white, rough-awned, long-haired rachilla type with brittle rachis.

As previously noted, the F_1 cross between Peatland and C.I. 4821 was grown in 1941 and additional F_1 plants were backcrossed to both parents in the green-

[1]Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa. Jour. paper J-1049. Project 655. Received for publication September 19, 1942.

[2]Research Professor of Farm Crops and Research Associate on leave of absence from the Agricultural College, Upsala, Sweden, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 106.

house during the winter of 1941–42. Both Peatland and C.I. 4821 were crossed to *H. agriocrithon* in the greenhouse during the fall and the F_1 plants grown during the winter to obtain seed for the F_2 generation. The F_2 generations of Peatland × C.I. 4821, Peatland × *H. agriocrithon*, and C.I. 4821 × *H. agriocrithon* and the backcrosses of (Peatland × C.I. 4821) Peatland and (Peatland × C.I. 4821) C.I. 4821, were grown in the field nursery in 1942. The segregating populations and parents were classified for brittle vs. normal rachis, black vs. colorless glumes, and long vs. short-haired rachilla.

EXPERIMENTAL RESULTS

The inheritance of the three major characters differentiating the parents are given below.

BRITTLE VS. NORMAL RACHIS

Twelve F_2 populations from the cross Peatland × C. I. 4821 were studied. All F_1 plants in this cross had brittle rachis suggesting, as shown previously by Ubisch (7), complementary factors for the expression of this character since both parents were homozygous for normal rachis. The number of plants with brittle and normal rachis and the chi square values given in Table 1 are in very close agreement with a 9:7 ratio for each of the 12 F_2 populations. The total chi square value of 8.06 (12 d.f.) corresponds to a P value between .7 and .8. The segregation for brittle rachis in the backcrosses of Peatland × C.I. 4821 to both parents is shown in Table 2. Although the segregating populations are very small because of unfavorable conditions in the greenhouse when the crosses were made, the results agree very well with the expected 1:1 ratio of brittle and normal rachis plants. The varieties Peatland and C.I. 4821 may then be designated, using the symbols recommended by Robert-

TABLE 1.—*Segregation for brittle and normal rachis in the F_2 generation from the cross Peatland × C.I. 4821 and chi square values for a 9:7 ratio.*

Culture, No.	Number of F_2 plants with		Chi square 9:7 ratio
	Brittle rachis	Normal rachis	
15–1	66	46	0.32
–2	89	53	2.32
–3	31	22	0.07
–4	24	14	0.96
15–5	30	18	0.76
–6	31	21	0.31
–7	37	23	0.61
–8	31	17	1.35
15–9	33	22	0.30
–10	12	5	0.97
–11	15	12	0.00
–12	24	20	0.09
Total	423	273	8.06

son, *et al.* (5), as Bt Bt bt_1 bt_1, and bt bt Bt_1 Bt_1. On the basis of complementary factors for brittle rachis, the F_1, Bt bt Bt_1 bt_1, should be brittle, the F_2 should segregate in a 9:7 ratio, and the backcross to both parents each segregate in a 1:1 ratio for brittle and normal rachis. All of the results obtained from this cross are in agreement with these ratios and thus verify the previous report by Ubisch (7).

TABLE 2.—*Segregation for brittle and normal rachis in the backcrosses of Peatland × C.I. 4821 and chi square values for a 1:1 ratio.*

Backcrosses	Number of plants with		Chi square 1:1 ratio
	Normal rachis	Brittle rachis	
(Peatland × C.I. 4821) Peatland	12	11	0.04
(Peatland × C.I. 4821) C.I. 4821	24	25	0.02

Crosses made between the two nonbrittle varieties and *H. agriocrithon* should reveal if the genes carried separately by the two varieties of *H. vulgare* are the same as those in the brittle rachis species. On the assumption that *H. agriocrithon* is Bt Bt Bt_1 Bt_1 each of the two F_2 populations from crosses with Peatland (Bt Bt bt_1 bt_1) and C.I. 4821 (bt bt Bt_1 Bt_1) should segregate for a single factor pair. The data given in Table 3 support the proposed genotype for *H. agriocrithon* since the chi square values are in agreement with a 3:1 ratio for both of the crosses. Since these results are the same as those reported by Biffen (3) in crosses between varieties of *H. vulgare* and *H. spontaneum*, it might be possible that the genes for brittle rachis in *H. agriocrithon* and *H. spontaneum* are allelic. Investigations bearing on this question are in progress in Sweden by the junior author.

TABLE 3.—*Segregation for brittle and normal rachis in the F_2 generation from crosses of Peatland and C.I. 4821 with H. agriocrithon.*

Cross	Number of plants with		Chi square 3:1 ratio
	Normal rachis	Brittle rachis	
Peatland × H. agriocrithon.....	78	27	0.11
C.I. 4821 × H. agriocrithon.....	157	61	1.04

LONG VS. SHORT-HAIRED RACHILLA

Previous studies on the inheritance of rachilla hair length summarized by Robertson, *et al.* (5) have shown a 3:1 ratio with long-haired rachilla dominant. Segregation for rachilla hair length was studied in crosses between Peatland (short-haired), C.I. 4821 (long-haired), and *H. agriocrithon* (long-haired). From the data given in Table 4, the F_2 and backcross generation of Peatland × C.I. 4821 and (Peatland × C.I. 4821) Peatland, respectively, show a good

agreement with the previously reported inheritance of this character. The F_2 generation of the cross Peatland × *H. agriocrithon* likewise gave a good fit to a 3:1 ratio with long-haired rachilla dominant. Since the cross C.I. 4821 × *H. agriocrithon* (long × long) gave only long-haired rachilla in the F_2 generation, it is evident that the genes for rachilla length in the two species are allelic.

TABLE 4.—*Segregation for long and short-haired rachilla in crosses between Peatland (ss), C.I. 4821 (SS) and H. agriocrithon (SS).*

Parentage	Generation	Number of plants with		Chi square	Ratio
		Long hair	Short hair		
Peatland × C.I. 4821........	F_2	511	185	0.93	3:1
(Peatland × C.I. 4821) Peatland....................	B.C.	11	12	0.04	1:1
Peatland × H. agriocrithon..	F_2	82	24	0.32	3:1
C.I. 4821 × H. agriocrithon..	F_2	218	0	—	—

BLACK VS. COLORLESS GLUMES

The inheritance of glume color in barley has been well established with black dominant in a 3:1 ratio. Classification for glume color in the present study was made in the F_2 and backcross to the recessive parent of Peatland × C.I. 4821 and in the F_2 generation of C.I. 4821 × *H. agriocrithon*. The data given in Table 5 show a single factor for black vs. white in the F_2 and backcross of Peatland × C.I. 4821 and (Peatland × C.I. 4821) Peatland, respectively. In the cross C.I. 4821 × *H. agriocrithon*, the F_2 population also segregated in a 3:1 ratio for black vs. white and in the F_2 generation of Peatland × *H. agriocrithon* only colorless glumes were obtained. The results indicate that the genes for glume color in *H. vulgare* and *H. agriocrithon* are also allelic.

TABLE 5.—*Segregation for black and white glume color in crosses between Peatland (bb), C.I. 4821 (BB), and H. agriocrithon (bb).*

Parentage	Generation	Number of plants with		Chi square	Ratio
		Black glumes	White glumes		
Peatland × C.I. 4821........	F_2	513	183	0.62	3:1
(Peatland × C.I. 4821) Peatland....................	B.C.	12	11	0.04	1:1
C.I. 4821 × H. agriocrithon..	F_2	170	48	1.04	3:1
Peatland × H. agriocrithon..	F_2	0	106	—	—

LINKAGE STUDIES

Previous studies on linkage relations of brittle rachis have not been reported. In these crosses it was possible to test for linkages with black vs. colorless glumes (group 2) and long vs. short-haired rachilla (group 5) in crosses of *H. agriocrithon* with C.I. 4821 and

Peatland, respectively. Since in either cross brittle rachis should segregate in a 3:1 ratio (Table 3), the chi square tests for independence was based on a 9:3:3:1 ratio with brittle rachis and either rachilla hair length or glume color. From the chi square values given in Table 6 it is concluded that the genes for brittle rachis are not linked with those for glume color or rachilla hair length. The chi square values of 2.08 and 1.16, corresponding to P values above .5, are in good agreement with the expected 9:3:3:1 ratio for independent inheritance.

TABLE 6.—*Factor interaction of brittle rachis with glume color and rachilla hair length and of glume color with rachilla hair length.*

Factor interaction	Crosses studied	Chi square value for 9:3:3:1
Brittle vs. Normal Rachis in Relation to		
1. Black vs. white glume color	*H. agriocrithon* × C.I. 4821	2.08
2. Long vs. short-haired rachilla	*H. agriocrithon* × Peatland	1.16
Black vs. White Glume Color in Relation to		
1. Long vs. short-haired rachilla	Peatland × C.I. 4821	2.42

Independent inheritance of glume color and rachilla hair length, although not previously reported, would be expected on the basis of their respective linkage groups. The chi square value of 2.42 (P = .5) verifies the independent inheritance of these two characters.

DISCUSSION

The study of crosses between *H. vulgare* and *H. agriocrithon* are of special interest in relation to the recent theory by Åberg (2) on the origin of the cultivated forms of barley. In this theory, it was proposed that the six-rowed tough rachis forms were developed from the six-rowed brittle rachis type and that the two-rowed types were derived from the six-rowed varieties at a subsequent period. The brittle rachis forms were considered to be primitive on the basis of anatomical features and advantages in distribution of seed. Brittle rachis forms also occur in *Secale* and *Triticum*.

The justification for a separate species on the basis of brittle vs. tough rachis when the two forms have the same chromosome number and freely intercross has been discussed by Åberg (2). From the data available in this study, the tough rachis varieties of *H. vulgare* could have been obtained from *H. agriocrithon* by a single gene mutation of either Bt Bt or Bt_1 Bt_1 to bt bt or bt_1 bt_1, since the single factor pair differentiates the major character of the two species. Mutation from the dominant brittle to the recessive normal or tough rachis has evidently occurred for both of the factor pairs as shown by the complementary gene action in the cross of Peatland and C.I. 4821. Thus, the cultivated varieties of six-rowed barley with tough rachis could very easily be obtained from *H. agriocrithon* as postulated by Åberg (2). Genetic relationship between this species

and *H. vulgare* have also been demonstrated in respect to allels for long-haired rachilla and glume color. Since segregation for rough and smooth awns did not occur (all three parents were rough awned), it may also be assumed that the genes for rough awn are also allelic in the two species. These facts give additional support to the genetic relationship between the two species.

SUMMARY

From a study of the cross Peatland × C.I. 4821, two tough rachis varieties of *H. vulgare*, complementary gene action was shown for brittle rachis. The F_1 generation was brittle, F_2 segregation fit a ratio of 9 brittle: 7 tough, and backcross ratios of 1:1 were obtained.

Crosses between the two varieties of *H. vulgare* with *H. agriocrithon*, a brittle rachis type, each gave a 3:1 ratio for brittle vs. tough, indicating that the two dominant genes for brittle rachis carried separately in the cultivated varieties were allelic to the two dominant genes in *H. agriocrithon.*

Ratios of 3:1 for black vs. white and long-haired vs. short-haired rachilla were obtained in the cross between the cultivated varieties and also in the crosses between the cultivated varieties and *H. agriocrithon.* Genes for colorless lemma and long-haired rachilla were shown to be allelic in the two species.

Brittle rachis was found to be inherited independently of glume color and rachilla hair length. Glume color and rachilla hair length were also independent in their inheritance.

The genetic relationship between *H. vulgare* and *H. agriocrithon* in relation to the phylogeny of the cultivated varieties of barley was discussed.

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INFLUENCE OF CROPPING, MANURE, AND MANURE PLUS LIME ON EXCHANGE CAPACITY, EXCHANGEABLE CALCIUM, pH, OXIDIZABLE MATERIAL, AND NITROGEN OF A FINE-TEXTURED SOIL IN EASTERN NEBRASKA[1]

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EFFECTS of cropping and fertilization on the chemical properties of soils have been the subject of extensive research. Whiteside and Smith (8)[3] have recently reviewed the literature concerning soil changes associated with cropping in humid areas of the United States. Prince, *et al.* (5), who worked with soil materials in cylinders, have reported the changes in several properties of a New Jersey soil during 40 years of nitrogenous fertilization. Metzger (3) has presented data concerning the effect of fertilizers, manure, and lime on several properties of a Kansas soil cropped to alfalfa. Merkle (2) has referred to numerous publications dealing with the after effects of fertilizers in his report of base exchange studies on the Pennsylvania Jordan field plots.

It is the purpose of this paper to report the effect of cropping, of applications of manure, and of applications of manure plus lime on exchange capacity, exchangeable calcium, pH, oxidizable material, and nitrogen of the soil at the fertility plots near Lincoln, Nebr. The soil of these plots is tentatively mapped as Marshall silty clay loam, but it has a heavier and more compact subsoil than is typical for that soil type. For the 71-year period ending with 1941, the mean annual precipitation at Lincoln was 26.8 inches. During the 16-year rotation period, 1921 to 1936, the mean annual precipitation was 24.3 inches, with annual amounts varying from 14.1 to 34.3 inches. About three-fourths of the precipitation occurs in the growing season, April to September, inclusive.

FERTILITY PLOTS

The fertility plots, established in 1921,[4] were designed for the purpose of studying the effect of manure and commercial fertilizers on the yields of corn, oats, wheat, and alfalfa during a 16-year rotation period. The plots were 28 feet wide, 0.1 acre in size, and were separated by an untreated but cropped alley, 7 feet wide. They were arranged in four parallel tiers, 46 plots each, every third plot being a check plot. The same order of treatment was followed in each tier, so that the manured and check plots being considered in this work made up a section of nine adjacent plots at the end of each of the four tiers. In the rotation,

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[3]Figures in parenthesis refer to "Literature Cited", p. 113.

[4]These plots were established by T. A. Kiesselbach, J. C. Russel, and Arthur Anderson.

alfalfa was grown for 4-year periods in each tier, only one tier being cropped to alfalfa at one time. During the other 12 years the crops were corn, oats, and wheat in that sequence. Manure was applied broadcast to wheat, oats, and corn before seedbed preparation and as a spring topdressing to alfalfa. The quantity of manure applied was calculated on the basis of 67% moisture. The entire field had been under cultivation for about 40 years previous to 1921.

For the work reported here, soil samples[5] were taken from the surface 6 inches in 1921 and in 1936. In each plot 13 sampling locations were determined at regular intervals by means of a wire. The three lines made by the wire in each plot were parallel to each other, but not to the sides of the plot, so that continuous sampling in old furrows or crop rows was avoided. These samples were composited, air-dried, sieved, and mixed before being stored in closed glass jars. All samples were analyzed after 1936.

ANALYTICAL METHODS

An ammonium acetate method, based chiefly on that of Schollenberger and Dreibelbis (6) and described by Peterson and Goodding (4), was used to determine the exchange capacity. Exchangeable calcium was determined by precipitating the calcium in the leachate as the oxalate and titrating it with potassium permanganate solution. Nitrogen was determined by a slightly modified Gunning method, about 0.1 gram of copper being used as a catalyst. Oxidizable material was determined by the Walkley and Black method as modified by Smith and Weldon (7). The hydrogen-ion concentration was determined with a quinhydrone electrode on a soil-water mixture in the ratio of 1 to 2.5. Inorganic carbon was determined by treatment with dilute perchloric acid, the carbon dioxide evolved being caught in barium hydroxide (7).

EFFECT OF CROPPING

In Table 1 are data for exchange capacity, exchangeable calcium, reaction, oxidizable material, and nitrogen for the original check plot samples and for those taken after 16 years of cropping. The average decrease in exchange capacity in the 12 plots as a result of 16 years of cropping was 0.88 M.E. per 100 grams, which is a percentage loss of 3.5. This decrease is not statistically significant,[6] but it does suggest a downward trend in exchange capacity. Presumably decreases in this property are a consequence of organic matter losses. The average decrease in oxidizable material is 0.38 M.E. per gram (statistically significant), which is 0.27% organic matter (7). If all of the decrease of exchange capacity is attributed to organic matter loss, the exchange capacity per 100 grams of the organic matter would be 326 M.E. Calculations based on that figure indicate that organic matter was responsible for 51.9% of the exchange capacity in 1921 and 50.2% in 1936. Exchange capacity values for these plots might also be altered by sheet erosion. The effect of the consequent increase in clay content of the surface 6 inches would be to produce

[5]The samples were taken by J. C. Russel and Arthur Anderson in 1921 and by H. F. Rhoades and C. E. Domingo in 1936.

[6]Differences which are at least twice the standard error of the difference are called "statistically significant". This is approximately the 5% level of significance.

a trend opposite to that resulting from the lowered organic matter content.

TABLE 1.—*Effect of 16 years of cropping on some chemical properties of the surface 6 inches of check plots.**

	Exchange capacity, M. E. per 100 grams	Exchangeable calcium, M. E. per 100 grams	pH	Oxidizable material, M. E. per gram	Nitrogen, %
Initial samples	24.86	13.83	5.92	5.67	0.184
Samples after 16 years	23.98	13.46	5.48	5.29	0.169
Difference	− 0.88	− 0.37	−0.44	−0.38	−0.015
Standard error of difference	0.88	0.60	0.06	0.15	0.004

*Initial samples were available from only 11 plots for the determination of exchangeable calcium, oxidizable material, and nitrogen. Consequently, in this table, the averages for these data for the later samples are also computed from only 11 plots. This explains the apparent discrepancy between these figures and those in Table 2 for all check plots.

Loss of exchangeable calcium over the 16-year period averaged 0.37 M.E. per 100 grams. The average percentage saturation by calcium was 55.6 in 1921, as compared with 56.1 in 1936. It would seem, then, that if the apparent decrease in the amount of exchangeable calcium is real, it is a consequence of loss of material capable of exchange reactions, rather than a lowering of the percentage level of exchangeable calcium.

The reaction data for the 1921 and 1936 samples indicate a statistically significant increase in hydrogen-ion concentration corresponding to 0.44 of a pH unit. Evidently the increase in exchangeable hydrogen ions has been at the expense of cations other than calcium, however.

Decreases in amounts of oxidizable material and of nitrogen over the 16-year period are small but statistically significant, 0.38 M.E. per gram for oxidizable material and 0.015% for nitrogen. All save one of these 11 check plots suffered a loss in oxidizable material, while all of them decreased in nitrogen content.

EFFECT OF MANURE

In Table 2 are the data for exchange capacity, exchangeable calcium, reaction, oxidizable material, and nitrogen for the manured and adjacent untreated plots. All samples were composites from the surface 6 inches, collected in 1936 after the 16-year rotation period. The check plots concerned were those discussed in connection with Table 1. Manure treatments included the following applications: 18 tons every fourth year, 12 tons every fourth year, 6 tons every second year, and 3 tons every year.

The variation among differences in exchange capacity of manured plots as compared with that of adjacent check plots was small. The range was from 0.57 to 0.75 M.E. per 100 grams. These average differences attributed to each treatment cannot be regarded as

TABLE 2.—*Effect of manure applications over a 16-year period on some chemical properties of the surface 6 inches of soil as measured by comparison with the soil of adjacent check plots.*

Treatment	No. of plots	Exchange capacity, M. E. per 100 grams	Exchangeable calcium, M. E. per 100 grams	pH	Oxidizable material, M. E. per gram	Nitrogen, %
None	4	24.18	13.53	5.53	5.20	0.160
18 tons every 4 years	4	24.93	13.88	5.61	5.98	0.186
Difference		+ 0.75	+ 0.35	+0.08	+ 0.78	+0.026
None	8	23.95	13.54	5.48	5.35	0.167
12 tons every 4 years	8	24.54	13.71	5.57	5.45	0.176
Difference		+ 0.59	+ 0.17	+0.09	+0.10	+0.009
None	4	23.73	13.55	5.44	5.50	0.174
6 tons every 2 years	4	24.30	13.83	5.58	5.63	0.184
Difference		+ 0.57	+ 0.28	+0.14	+0.13	+0.010
None	4	24.03	13.75	5.48	5.23	0.167
3 tons each year	4	24.63	13.80	5.57	5.48	0.181
Difference		+ 0.60	+ 0.05	+0.09	+0.25	+0.014
All check plots	12	23.98	13.61	5.48	5.31	0.167
All manured plots	20	24.59	13.79	5.58	5.60	0.181
Difference		+ 0.61	+ 0.18	+0.10	+0.29	+0.014
Standard error of difference		0.78	0.52	0.05	0.10	0.003

characteristic of the different applications. The average exchange capacity of the manured plots was 0.61 M.E. per 100 grams greater than that of the check plots, but this difference is not statistically significant. This average difference is slightly less than the decrease in exchange capacity produced by 16 years of cropping on the check plots. If this difference were the result of only one factor, the difference in average organic matter content (0.29 M.E. per gram, or 0.20%), the exchange capacity of the organic matter would be 305 M.E. per 100 grams. This corresponds reasonably well with the value 326 obtained from the calculation based on the assumption that the lowering of the exchange capacity, during 16 years of cropping of the check plots, was a consequence of loss of organic matter. These calculations indicate that even small differences between properties of treated and untreated plots may be real, although not statistically significant.

Treatment with 3 tons of manure per acre every year produced a difference of 0.05 M.E. per 100 grams of exchangeable calcium. The largest difference between treated and untreated plots was 0.35 M.E.

per 100 grams for the plots manured with 18 tons per acre every fourth year. It is doubtful, however, whether any significance should be attached to this variation among different treatments. The average exchangeable calcium value for all manured plots was 0.18 M.E. per 100 grams higher than the average value for adjacent check plots. This difference is not statistically significant. The average percentage saturation by calcium, calculated from the figures in Table 2, is 56.8 in the check plots and 56.1 in the manured plots.

Relatively similar differences in pH resulted from the different manure applications. The pH corresponding to the average hydrogen-ion concentration of the manured plots was 5.58, as compared with 5.48 for the check plots. This difference is just at the level of statistical significance.

A difference of 0.78 M.E. per gram of oxidizable material and 0.026% nitrogen resulted from the manure application of 18 tons every fourth year. These differences are well above those credited to the other applications. They are also greater than the losses ascribed to 16 years of cropping (Table 1). The average differences between the manured and check plots with respect to oxidizable material and nitrogen, although small, were statistically significant. Bertramson and Rhoades (1) found no indication that these differences were reflected in the physical properties of these soils. Their analyses included upper and lower plastic limits, scouring point, moisture equivalent, hygroscopic coefficient, maximum water capacity, volume weight, and aggregate analysis.

EFFECT OF MANURE AND LIME

In Table 3 are the data for exchange capacity, exchangeable calcium, reaction, oxidizable material, and nitrogen for the limed and manured plots, and the adjacent check plots.

TABLE 3.—*Effect of applications of lime and manure over a 16-year period on some chemical properties of the surface 6 inches of soil as measured by comparison with the soil of adjacent check plots.*

Treatment	No. of plots	Exchange capacity, M. E. per 100 grams	Exchangeable calcium, M. E. per 100 grams	pH	Oxidizable material, M. E. per gram	Nitrogen, %
None	4	24.03	13.68	5.48	5.20	0.167
M 6/2; L 2/4*	4	25.80	21.00†	6.89	5.67	0.181
Difference		+ 1.77	+ 7.32	+1.41	+0.47	+0.014
Standard error of difference		2.20	1.63	0.34	0.28	0.007

*Manure applied at the rate of 6 tons every 2nd year; lime at the rate of 2 tons every 4th year.

†The average carbonate (as $CaCO_3$) content of the limed plots was 0.12%. If all of it dissolved in the process of extraction in the determination of exchangeable calcium, there would result an increase in the apparent exchangeable calcium of 2.4 M.E. per 100 grams.

Although this treatment produced an exchange capacity of 1.77 M.E. per 100 grams greater than that for the check plots, the difference is not statistically significant for four plots. Exchangeable calcium of the check plots was 13.68 M.E. per 100 grams, as compared with 21.00 for the treated plots. Part of this difference is ascribable to solution of free calcium carbonate of the treated plots during the process of leaching with ammonium acetate solution. If one assumes that all of this calcium carbonate is transferred to the leachate containing the exchangeable calcium, the effect of manure plus lime on the calcium level is still large, producing the difference between 56.9% and 72.1% saturation by calcium. The effect of this treatment on the reaction was statistically significant, the pH of the treated plots being 6.89, as compared with 5.48 for the check plots.

The difference in oxidizable material between the treated and check plots was 0.47 M.E. per gram, a value which approaches statistical significance. The difference of 0.007% in nitrogen is barely significant.

These limed and manured plots might also be compared with those receiving a like amount of manure, 6 tons every second year (Tables 2 and 3). The calculated effect of lime alone on exchangeable calcium and pH is of course large. The calculated effect of lime alone on exchange capacity is also large, but it is doubtful whether the difference is reliable. The data for the effect of lime alone on oxidizable material and nitrogen are contradictory, but they do not support the apparent effect of lime on the exchange capacity.

SUMMARY

Soil samples were taken from the Nebraska soil fertility plots at the time of establishment (1921) and at the end of a 16-year rotation period (1936). Included in the work reported here were samples from the surface 6 inches of plots treated with manure and with manure plus lime, as well as those from adjacent check plots. All samples were analyzed after 1936. Analyses made on these samples included exchange capacity, exchangeable calcium, pH, oxidizable material, and nitrogen. Results of the study may be summarized as follows:

1. In the surface 6 inches of the check plots, 16 years of cropping resulted in small but not statistically significant decreases in exchange capacity and content of exchangeable calcium. The pH values, the content of oxidizable material, and the content of nitrogen had decreased significantly.

2. Differences between the manured and check plots in exchange capacity and content of exchangeable calcium were not statistically significant. A barely significant difference in the pH value was found. Significant differences between these plots were found for the content of oxidizable material and of nitrogen.

3. As compared with the check plots, those receiving manure plus lime did not exhibit a statistically significant difference in the exchange capacity. The difference between these plots in content of oxidizable material was just below the level of significance, whereas the

difference in content of nitrogen was barely significant. However, marked differences (statistically highly significant) were found between these plots in the content of exchangeable calcium and in the pH values. The check plots had a pH of 5.5 and were 57% saturated by exchangeable calcium; those receiving manure plus lime had a pH of 6.9 and were 72% saturated by exchangeable calcium.

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RESPONSE OF WHEAT VARIETIES TO DIFFERENT LEVELS OF SOIL PRODUCTIVITY: I. GRAIN YIELD AND TOTAL WEIGHT[1]

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WHEAT breeding and variety test plots usually are conducted on a single level of soil productivity. Results obtained from such experiments are used to appraise new strains and recommend varieties for a particular region. However, the region often represents many soil types and farms varying widely in productivity. Any important differences in the response of varieties to different levels of soil fertility would greatly complicate the testing program. Only if such differences are nonexistant or quite unimportant can the relative value of different varieties tested under a single set of soil conditions be regarded as reliable and conclusive.

The present study reports the response, in grain yield and total weight, of five varieties of wheat to different levels of soil fertility established by the addition of mineral fertilizers. The tests were conducted on Plainfield fine sand, Crosby silt loam, and Alford silt loam soils during the 5-year period of 1937–41, inclusive.

REVIEW OF LITERATURE

Many reports have been published involving the interaction of varieties with season, climate, location, and various soil nutrients, but only the more pertinent papers dealing with the response of varieties to different levels of soil fertility will be discussed.

Working with potatoes, Fisher and Mackenzie (2)[3] found no significant variation in the response of different varieties to manurial treatments. Mooers (6) pointed out definite corn yield interactions between variety and soil fertility.

Stringfield and Salter (7) set up a 3-year rotation of corn, oats, and winter wheat in which several varieties of each crop were planted across the four levels of soil fertility that were established by the addition of fertilizer and manure. Reporting the results with corn only, they found significant differential varietal response in yield among the different levels in two of the four seasons but not in the experiment as a whole.

With wheat and oats, Lamb and Salter (4, 5) reported that of all the variety-level interactions for total yield and grain yield, by seasons, only the total yield in wheat in the 1930–31 season was significant. Considering all seasons together, the variety-level interactions were significant in wheat but nonsignificant in oats. Later, soybeans replaced oats in this rotation, and reporting on four years results Cartter and Hopper (1) stated that "... the fertility levels were without much effect on the rank of the varieties with respect to yield, ...".

Hurst, Skuderna, and Doxtator (3) report a nonsignificant variety-level

[1]Journal Paper Number 47, of the Purdue University Agricultural Experiment Station, Lafayette, Ind. Received for publication September 10, 1942.

[2]Associate in Agronomy. The writer wishes to express his appreciation to S. R. Miles, Associate in Agronomy, for suggestions given in the statistical analysis.

[3]Reference by number in parenthesis is to "Literature Cited", p. 123.

Tables 3 and 4 present the analysis of variance, by seasons, of grain yield and total weight data, respectively. Only varieties, fertility levels, and varieties × levels interactions were considered. However, the mean squares due to blocks were highly significant, indicating that a part of the soil variability was controlled and eliminated in the calculations.

It will be noted in Tables 3 and 4 that the mean squares for fertility levels and varieties are either significant or highly significant. This indicates that, in all seasons and on each soil type, there were significant differences in grain yield and total weight among fertility levels and highly significant differences among varieties. Since the mean squares (Table 3) for interaction of varieties with fertility levels in the majority of cases exceed the mean squares for error significantly, it is apparent that some varieties reacted in a different manner in

TABLE 3.—*Summary of mean squares, by seasons, from analysis of variance of yield data for five varieties of wheat grown on three levels of soil fertility on each of three soils types for 4 or 5 years.*

Item	Degrees of freedom	Mean square				
		1937	1938	1939	1940	1941
		Plainfield Fine Sand, Sand Field				
Between blocks:						
Fertility levels..	2	248,973*	198,829†	75,017*	542,356†	236,511*
Error (1)........	2	3,451	1,701	856	178	3,877
Within blocks:						
Varieties........	4	10,250†	5,907†	25,924†	13,929†	18,589†
Varieties × levels interaction....	8	1,239†	1,689†	334	1,572†	4,263†
Error (2)........	132	465	324	461	453	465
		Crosby Silt Loam, Soils and Crops Farm				
Between blocks:						
Fertility levels...	2	——	382,556*	239,957†	337,715*	311,862†
Error (1)........	2	——	5,783	1,619	11,047	507
Within blocks:						
Varieties........	4	——	38,554†	14,415†	39,927†	25,159†
Varieties × levels interaction....	8	——	670	1,718*	1,401	2,878*
Error (2)........	132	——	904	777	940	1,058
		Alford Silt Loam, Knox County Farm				
Between blocks:						
Fertility levels...	2	562,065*	193,400*	434,161*	704,042†	614,036*
Error (1)........	2	6,234	3,861	11,839	4,828	9,710
Within blocks:						
Varieties........	4	36,396†	7,870†	14,754†	123,365†	7,185†
Varieties × levels interaction....	8	2,219*	3,349†	1,317	805	1,385
Error (2)........	132	937	826	968	942	1,015

*Exceeds the 5% level of significance.
†Exceeds the 1% level of significance.

certain years and on different soils. On the Plainfield fine sand the variety × fertility level interaction was highly significant in four of the five seasons, while on the Alford silt loam it was significant only twice during the same period. For total weight (Table 4) the variety-level interactions were significant in only 5 of the 14 comparisons. The greater number of significant interactions for grain yield over those for total weight might indicate a greater differential response in the translocation phases than in the vegetative phases of plant development.

TABLE 4.—*Summary of mean squares, by seasons, from analysis of variance of total weight data for five varieties of wheat grown on three levels of soil fertility on each of three soil types for 4 or 5 years.*

Item	Degrees of freedom	Mean square 1937	1938	1939	1940	1941
		Plainfield Fine Sand, Sand Field				
Between blocks:						
Fertility levels.	2	2,498,925†	1,921,548†	548,318†	6,384,948†	2,310,918†
Error (1)......	2	17,561	4,020	3,099	4,044	21,871
Within blocks:						
Varieties......	4	37,285†	32,588†	138,811†	68,336†	61,943†
Varieties × levels interaction	8	4,831	8,918†	1,968	4,519	20,201†
Error (2)......	132	4,303	2,162	4,220	3,994	2,366
		Crosby Silt Loam, Soils and Crops Farm				
Between blocks:						
Fertility levels.	2	—	5,089,998*	3,378,740†	7,408,092†	6,100,186†
Error (1)......	2	—	72,714	23,674	43,710	35,709
Within blocks:						
Varieties......	4	—	148,955†	147,006†	279,494†	96,070†
Varieties × levels interaction	8	—	11,428	9,933	8,661	19,999*
Error (2)......	132	—	8,660	8,721	8,394	7,983
		Alford Silt Loam, Knox County Farm				
Between blocks:						
Fertility levels.	2	7,318,359†	2,256,415*	9,070,596†	7,642,382†	12,401,521†
Error (1)......	2	43,475	93,030	72,696	135,100	87,825
Within blocks:						
Varieties......	4	170,575†	43,591†	132,606†	97,142†	47,821†
Varieties × levels interaction	8	28,730*	28,358*	7,086	7,994	6,030
Error (2)......	132	13,385	10,700	8,096	8,198	10,580

*Exceeds the 5% level of significance.
†Exceeds the 1% level of significance.

In Table 5 are reported the mean squares from analysis of variance of yield and total weight data calculated on the 4- or 5-year averages. Seasons, varieties, fertility levels, and interactions among these are involved. The results of the analyses of variance show that the differences among varieties and fertility levels, when the data for grain yields and total weights on each soil type for all seasons are taken together, are significant.

TABLE 5.—*Summary of mean squares from analysis of variance of average yield and total weight data for five varieties of wheat grown on three levels of soil fertility on each of three soil types during 1937–41, inclusive.*

Item	Degrees of freedom	Mean squares					
		Yield			Total weight		
		Plainfield fine sand	Crosby silt loam†	Alford silt loam	Plainfield fine sand	Crosby silt loam†	Alford silt loam
Seasons	4	312.08‡	110.56‡	190.30‡	263,173‡	120,377‡	190,465‡
Varieties	4	28.60‡	38.53‡	14.76	11,770*	28,801‡	13,626
Fertility levels	2	708.46‡	837.60‡	1,576.62‡	794,248‡	1,433,833‡	2,412,704‡
Seasons × varieties	16	5.33‡	13.26‡	9.36‡	2,705‡	5,322‡	4,787‡
Varieties × levels	8	2.23*	2.38*	2.78‡	1,301‡	1,361	1,435
Seasons × levels	8	21.74‡	2.90	23.86‡	29,160‡	10,437‡	41,646‡
Seasons × varieties × levels	32	0.96	0.82	0.81	349	658	944

*Exceeds the 5% level of significance.
†Includes the 4 years, 1938–41.
‡Exceeds the 1% level of significance.

The variety × level interaction is the most important phase of this study. In so far as grain yield is concerned the significant mean squares for variety × fertility level interaction indicate that varieties respond differently to various levels of soil productivity. This interaction is mathematically significant only on the Plainfield fine sand when total weights are considered. The results shown in Table 5 substantiate also the well known facts that great differences exist among seasons, that varieties respond differently in different seasons, and that various soil fertility levels do not yield uniformly in all seasons.

Since the results obtained indicate that, in yield, varieties respond differently to a series of fertility levels, it seemed desirable to determine the nature of this differential behavior. In order to illustrate graphically the differential response, a slightly different method was used to study this interaction. The fact that the differences among varieties and among fertility levels were rather large and significant makes these data well suited for this inquiry.

The determination of the differential response of wheat varieties in grain yield to fertility levels was accomplished by the "proportion" calculations used in chi-square analysis. The two-way table was used to find the "expected values". For example, the "expected" average yield for Purdue No. 1 on low level (1937–41, Table 1) is the product of the sums of 5-year averages, Purdue No. 1 and low level, divided by the grand total, or $(61.6 \times 71.2)/307.5 = 14.26$. The other theoretical yields for every variety on each level were calculated

in a similar manner. The difference between the theoretical and actual yields in the example cited is (14.5 minus 14.26) + 0.24. Plus deviations indicate a response more favorable than the average and minus deviations indicate the variety was poorer in response than the average for that particular fertility level. If the difference is zero, there is no discrepancy.

In Fig. 2 are given for each variety and fertility level the deviations, shown as columns, calculated on the averages of 4 or 5 years data.

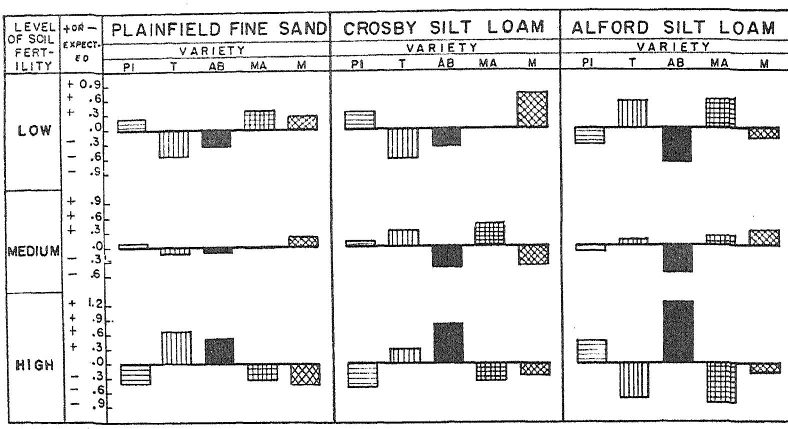

FIG. 2.—Relative response in yield of five varieties of wheat to three levels of soil fertility on each of three soil types. Plus bars indicate a response more favorable than the average and negative bars indicate the variety was relatively poorer for that particular level of fertility.

An examination of the deviations reveals that the wheat varieties tend to fall into several distinct response groups. American Banner produced relatively less grain on the low and medium levels of fertility and more wheat on the high level than the other varieties. On the other hand, Michigan Amber and Michikof yielded higher on the poorer treated soils but relatively lower on the high level of fertility. The differential response of these three varieties to levels has been very consistent on each soil type studied. Purdue No. 1 and Trumbull not only seem to belong to another response group, but also react in a reverse manner to each other. Purdue No. 1 responded in a manner similar to Michikof when grown on the Plainfield fine sand and Crosby silt loam soils, but like American Banner on the Alford silt loam. Trumbull, however, responded similarly to American Banner on the Plainfield and Crosby soils but like Michigan Amber on the Alford silt loam. Similarly prepared histograms, based on single year data, agree very closely with those shown in Fig. 2 in which the averages of four or five seasons data were combined.

Varietal adaptation might have affected the behavior of some of the varieties to different fertility levels since the experimental farms are located in the northern and southern part of the state, some 200 miles apart. On the basis of the average yields shown in Table 1, it

will be noted that even though American Banner ranked first at all levels when grown on both the Plainfield and Crosby soils and intermediate or last on the Alford silt loam, yet its relative response to fertility levels was the same at all locations. Likewise, Michigan Amber and Michikof ranked the lowest in average yield at all levels but reacted consistently to fertility levels at all locations. The opposite response to fertility levels between Purdue No. 1 and Trumbull does not appear to be related to their yielding ability. Trumbull produced greater yields than Purdue No. 1 when grown on the Plainfield sand but yielded significantly less at all levels on the Crosby soil. No significant differences in yield were found between these two varieties on the Alford silt loam.

The results reported have shown that varieties of wheat respond differently to various levels of soil fertility established by the addition of mineral fertilizers. The varieties studied tended to fall into distinct response groups. Some of the wheat varieties yielded relatively higher on the heavier fertilized plots, while others were relatively more efficient or better feeders when grown on the low-fertility plots. However, the data showed that the highest yielding variety ranked first in yield on all fertility levels, while the low-yielding varieties usually produced the least amount of grain on all levels of fertility. For yield, therefore, it appears that the magnitude of the interaction or differential response of wheat varieties to fertility levels found in this study, although significant, is quite small. However, large variety × level interactions could not be expected since small differences in yield exist between well-adapted wheat varieties.

SUMMARY

Grain yield and total weight (straw and grain) data are reported for five varieties of wheat grown on three levels of soil fertility on each of three soil types during the 5-year period of 1937–41, inclusive.

Analyses of variance for grain yield and total weight by individual years and all seasons together indicate that, on each soil type, the differences due to variety and fertility are significant or highly significant.

Differential varietal response in grain yield between the different fertility levels was significant in the majority of cases. For total weight, the variety × fertility level interactions were significant only in 6 of the 17 comparisons.

The wheats studied tended to fall into distinct response groups. Some varieties yielded relatively higher on the well-fertilized plots, while others were relatively more efficient when grown on the low-fertility plots.

While the variety × fertility level interactions for grain yield are significant, the interactions are not great enough to change yield ranks. Therefore, the same adapted variety would be recommended for all productivity levels of a soil.

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THE COMPARATIVE PERFORMANCE OF ALFALFA VARIETIES IN NURSERY AND FIELD PLOTS IN IRRIGATED SOIL INFESTED WITH *PHYTOMONAS INSIDIOSA*[1]

Ralph M. Weihing and D. W. Robertson[2]

PRELIMINARY results and recommendations from an experiment designed to determine the types of nursery plots that will give results comparable to those obtained from field plots in alfalfa experiments were reported from the Colorado Agricultural Experiment Station by Weihing and Robertson.[3] Since then, yield data for two more years, as well as data on other agronomic characters, have been obtained. After 3 years of harvesting for hay the plots have been discarded because the stands of wilt-susceptible varieties were severely depleted by death of infected plants. This final report is prepared because fewer types of nursery plots gave results comparable to field plots in the second and third years than for the first year of harvesting, i.e., the year after planting.

Tysdal and Kiesselbach[4] at the Nebraska Agricultural Experiment Station compared the two varieties, Hardistan and Ladak, in field plots and several types of nursery plots on nonirrigated land near Lincoln, Nebr. They recommended as most serviceable for advanced nursery testing: "(1) Solid-drilled five to eight rows spaced 7 inches apart, with a 12- to 14-inch alley between border rows, or (2) solid-drilled three to five rows spaced 12 inches apart with an 18-inch alley between border rows. Since removing border rows is difficult and expensive with this crop and since very little error has been found with such plats due to border effect, it is suggested that the entire plat may be harvested for yield, with the possible exception of removing border rows in case adjacent stands are decidedly different . . . The plats may be 16 feet or more in length, depending upon circumstances, and the alley space should be included in the plat area. Single rows spaced 18 to 24 inches apart are permissible for preliminary nursery testing".

Weihing and Robertson[5] compared five varieties, varying in susceptibility and resistance to bacterial wilt caused by *Phytomonas insidiosa*, L. McC., on irrigated, wilt-infected soil near Fort Collins, Colo., in field plots and several types of nursery plots. The following recommendations were made after analyzing yields for one cutting in 1938 and three cuttings in 1939: "Any one of the following types

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[2]Assistant Agronomist and Agronomist, respectively.

[3]Weihing, Ralph M., and Robertson, D. W. Forage yields of five varieties of alfalfa grown in nursery rows and field plots. Jour. Amer. Soc. Agron., 33:156–163. 1941.

[4]Tysdal, H. M., and Kiesselbach, T. A. Alfalfa nursery technic. Jour. Amer. Soc. Agron., 31:83–98. 1939.

[5]See footnote 3.

of nursery plots is suggested for precise testing under irrigation: Single-row plots 3 feet apart; three-row plots, 20 inches between rows, 20-inch alleys; and five-row plots, 12 inches between rows, 20-inch alleys. These plots require no more replications than the field plots. It is suggested that the entire plot be harvested for yield since border effect and inter-plot competition did not noticeably affect the comparability of yields between these nursery plots and the field plots". The center 16 feet of 18-foot rows were harvested for yield.

ARRANGEMENT AND CARE OF EXPERIMENT

The five varieties, Hardistan, Meeker Baltic, Ladak, Nebraska Common, and Grimm were seeded in the spring of 1938 at the rate of 10 pounds per acre in all types of plots. The seeding of the field plots was with a standard grain drill of 7-inch spacing and of the nursery rows by hand. Since the Latin square design was used, five replications of each variety were necessary.

The field plots were 1/20 acre in size. In all cases the center 16 feet of the 18-foot nursery rows were harvested for yield. The five types of nursery plots were: (1) Single rows 3 feet apart; (2) single rows 20 inches apart; (3) three-row plots 20 inches between rows with 20-inch alleys, using the middle row and the three rows; (4) three-row plots 12 inches between rows with 20-inch alleys, using the middle row and the three rows; and (5) five-row plots 12 inches between rows with 20-inch alleys, using the middle row, the three middle rows, and the five rows. Buffer rows were used when needed. Considering all possible single-row, three-row, and five-row yields, this experiment permits comparison of the five varieties in nine types of nursery plots with the field plots. The arrangement of part of the plots is shown in a previous publication.[6]

Because the nursery rows were kept free from weeds during the summer of 1938, the alfalfa made enough growth to permit one cutting that season. In 1939, 1940, and 1941 all plots were harvested three times each year on the usual dates for cutting alfalfa in the Fort Collins area (about June 15, July 25, September 15). All yields were computed in tons per acre of oven-dry forage. The oven-dry weights were obtained in 1938 and 1939 by reducing air-dry plot weights to oven-dryness from 10-gram samples drawn from the ground air-dry forage of each plot. Studies conducted during 1938 and 1939[7] showed that within cuttings all varieties of this experiment when air-dry contained nearly equal amounts of dry matter. Accordingly, in 1940 and 1941 the oven-dry weights were computed from air-dry plot weights corrected to oven-dryness from the average percentage dry matter in several samples taken during weighing.

Each season the plots were irrigated three times, which was considered sufficient for normal growth. The experiment was discontinued after the last cutting in 1941 because the stands in the field plots and part of the nursery plots of the wilt-susceptible varieties, Meeker Baltic, Grimm, and Nebraska Common, were too thin for another year of harvesting.

STATISTICAL METHODS

The performance of each variety in each type of plot for various agronomic characteristics is represented by the average of its five plots. An analysis of

[6]See footnote 3.

[7]WEIHING, RALPH M. Green and air-dry weights for determining hay yields of varieties of alfalfa. Jour. Amer. Soc. Agron., 34:877–882. 1942.

variance was used to compare the performance of varieties in each type of nursery plots with the performance of varieties in the field plots. The following analysis was used for each of the 10 types of plots:

Variance due to	Degrees of freedom
Blocks	4
Varieties	4
Columns	4
Error	12
Total	24

The following example illustrates how the field plots were compared with each of the nine types of nursery plots:

Variance due to	Degrees of freedom	F*
Varieties	4	varieties/varieties × types of plots
Varieties × types of plots	4	varieties × types of plots/error
Error	24	

*SNEDECOR, GEORGE W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa: Collegiate Press, Inc. 1934.

A significant F value for varieties/varieties × types of plots shows that the difference between varietal means of both tests are significantly greater than the interaction of varieties × types of plots and a significant F value for varieties × types of plots/error suggests that the varieties did not yield relatively the same in the type of nursery plots and field plots compared. Yields and other agronomic data were compared in this manner.

The number of replications necessary to make 5% of the general mean equal to 2 times the standard error of a difference was computed from the yield data for each type of plot for each year. The formula used for computation was $\sqrt{n} = \dfrac{2\sqrt{2}\ \text{S.E.}}{5}$, in which the denominator represents 5% of the mean; S.E., the standard error of a single determination in percentage of the general mean; and n, the number of replications.

FORAGE YIELDS

In 1938, the year of seeding, the nursery plots were harvested once. The field plots were not cut. The next 3 years all plots were mowed three times a year. The annual acre yields of the nine types of nursery plots and of the field plots are given in Table 1.

The yields in tons per acre of the five varieties in 1938 in the nine types of nursery plots, ranked in order of high to low yields, were as follows: Ladak, Meeker Baltic, Grimm, Nebraska Common, and Hardistan. In seven of the nine types the ranking was the same. In the other two types minor changes occurred.

In 1939 the order of varieties from high to low yields for the 10 types of plots were as follows: Meeker Baltic, Nebraska Common, Grimm, Ladak, and Hardistan. While this order was changed in 3

TABLE 1.—*The yield in tons per acre of oven-dry hay of five varieties of alfalfa seeded in field and nursery plots, 1938–41.*

Varieties	1/20 acre field plots	Nursery plots								
		1-row plots 3 feet apart	20-in. rows, 20-in. alleys			12-in. rows, 20-in. alleys				
			1-row plots	3-row plots		3-row plots		5-row plots		
				Middle row	3-rows	Middle row	3-rows	Middle row	Middle 3 rows	5 rows
One Cutting, 1938										
Ladak	—	1.23	1.72	1.68	1.69	1.95	2.13	1.79	1.92	2.03
Meeker Baltic	—	1.10	1.49	1.47	1.49	1.76	1.96	1.62	1.69	1.79
Grimm	—	0.99	1.40	1.36	1.33	1.64	1.74	1.54	1.49	1.57
Nebraska Common	—	0.93	1.26	1.30	1.25	1.44	1.59	1.33	1.45	1.54
Hardistan	—	0.84	1.24	1.22	1.22	1.43	1.60	1.38	1.37	1.51
2 S.E. diff	—	0.05	0.08	0.12	0.12	0.14	0.10	0.16	0.11	0.06
Three Cuttings, 1939										
Meeker Baltic	5.78	4.50	5.97	5.56	5.72	6.13	7.49	6.07	6.38	7.10
Nebraska Common	5.51	4.45	5.51	5.36	5.57	5.91	7.40	5.60	5.95	6.89
Grimm	5.41	4.41	5.39	5.38	5.42	5.83	7.12	6.19	5.93	6.67
Ladak	5.28	4.30	4.46	5.21	5.10	5.76	6.42	5.54	5.80	6.26
Hardistan	5.17	3.83	4.87	4.91	5.03	4.99	6.32	5.60	5.47	6.21
2 S.E. diff	0.30	0.16	0.44	0.31	0.18	0.35	0.35	0.53	0.37	0.32

					Three Cuttings, 1940					
Nebraska Common	5.16	4.81	5.83	5.43	5.80	5.64	7.26	6.06	6.10	7.01
Hardistan	5.12	4.55	5.53	5.37	5.49	5.56	6.91	5.93	5.80	6.67
Meeker Baltic	5.07	4.68	5.68	5.45	5.59	5.69	6.86	5.83	5.95	6.74
Grimm	4.99	4.54	5.28	5.25	5.33	5.51	6.70	5.95	5.94	6.66
Ladak	4.81	3.84	3.82	5.11	4.79	5.23	5.65	5.44	5.52	5.94
2 S.E. diff	0.24	0.24	0.47	0.27	0.17	0.44	0.24	0.71	0.31	0.34
					Three Cuttings, 1941					
Hardistan	4.01	3.88	5.14	4.27	4.64	4.77	6.02	5.00	4.76	5.67
Ladak	3.73	3.57	3.37	4.36	4.04	4.54	4.94	4.48	4.58	4.92
Nebraska Common	3.43	4.25	5.20	4.60	4.98	4.94	6.05	4.22	4.43	5.06
Meeker Baltic	3.30	4.04	4.15	4.49	4.39	4.57	5.34	3.77	4.22	4.61
Grimm	3.10	3.77	4.26	4.73	4.75	4.85	5.76	4.11	4.25	4.53
2 S.E. diff	0.39	0.50	0.56	0.41	0.25	0.81	0.24	0.82	0.49	0.39
					Average, 1939–41					
Hardistan	4.76	4.09	5.18	4.85	5.05	5.10	6.42	5.51	5.34	6.18
Meeker Baltic	4.72	4.40	5.27	5.17	5.23	5.46	6.56	5.22	5.52	6.15
Nebraska Common	4.70	4.50	5.52	5.13	5.45	5.50	6.90	5.29	5.49	6.32
Ladak	4.60	3.90	3.88	4.89	4.64	5.18	5.67	5.15	5.30	5.70
Grimm	4.50	4.24	4.98	5.12	5.17	5.40	6.52	5.42	5.37	5.95
2 S.E. diff	0.23	0.25	0.37	0.28	0.13	0.35	0.19	0.55	0.32	0.29

of the 10 types of plots, only that for the middle row of the five-row plots was seriously out of line.

In 1940 and 1941 the order of varieties was less constant than in 1938 and 1939. It was so different in some cases that the yields from certain types of nursery plots were not a reliable index of performance in field plots. This fact is clearly shown in Table 2, which contains F values from an analysis of variance.

TABLE 2.—*The F value (varieties/varieties × types of plots) and the F value (varieties × types of plots/error) for the yields of five varieties of alfalfa grown in field plots and nursery plots, 1939–41.*

Field plots compared with	Varieties/varieties × types of plot†				Varieties × types of plots/error‡			
	1939	1940	1941	1939–41	1939	1940	1941	1939–41
Single Rows								
Rows 3 ft. apart....	8.26*	4.17	0.64	1.41	1.93	4.22**	4.78**	3.96*
Rows 20 in. apart....	4.22	1.94	1.32	1.35	4.32**	13.20**	10.59**	15.23**
3-Row Plots, 20 Inches Between Rows, 20-Inch Alleys								
Middle rows	21.66**	30.62**	0.14	0.65	0.44	0.15	7.08**	2.48
Three rows	28.10**	4.44	0.55	1.39	0.64	5.41**	12.20**	9.58**
3-Row Plots, 12 Inches Between Rows, 20-Inch Alleys								
Middle rows	5.62	16.58**	0.70	0.75	3.38*	0.19	1.83	2.24
Three rows	4.85	2.49	1.06	1.28	4.53**	15.53**	12.95**	17.64**
5-Row Plots, 12 Inches Between Rows, 20-Inch Alleys								
Middle rows	3.28	8.52*	13.40*	1.25	1.49	0.23	0.45	0.65
Three middle rows..	24.04**	7.46*	15.06*	2.14	0.46	0.81	0.45	0.67
Five rows..	12.41*	3.93	15.82*	2.92	1.29	3.33*	1.04	2.04

†D.F., 4 and 4: F for 5% point = 6.39; for 1% point = 15.98.
‡D.F., 4 and 24: F for 5% point = 2.78; for 1% point = 4.22.

As previously stated, a significant F value for varieties/varieties × types of plots shows that the differences between varietal means of both tests are significantly greater than the interaction of varieties × types of plots, while a significant F value for varieties × types of plots/error suggests that the varieties did not yield relatively the same in the type of nursery plots and field plots compared (Table 2). The analysis indicates that as the stands became older, fewer types of nursery plots yielded relatively the same as the field plots. The first year after seeding the following types of nursery plots appeared reliable for predicting field performance: (1) Single rows 3 feet apart; (2) middle rows of three-row plots, 20 inches between rows, 20-inch alleys; (3) middle rows of five-row plots, 12 inches between rows, 20-inch alleys; (4) three rows of five-row plots, 12 inches between rows, 20-inch alleys; and (5) five rows of five-row plots, 12 inches

between rows, 20-inch alleys. After 3 full years of harvesting, however, the only nursery plots reliable for predicting field yields of varieties were the middle row, the three middle rows, and the five rows of the five-row plots. Accordingly, from a yield point of view, it appears advisable to use nursery plots with five or more rows spaced about 12 inches apart and 16 feet or more in length to predict field performance of alfalfa varieties grown on irrigated soil infested with the alfalfa wilt organism. The suggested alley space between sides of plots is 2 feet and between ends of plots 3 feet. Also, there seems to be no necessity for discarding ends and borders of plots, except when adjacent stands are different, because border effect and inter-plot competition have not caused serious errors. The alley space should be included in the plot area. Plots of these dimensions are readily handled with machinery.

Table 3 has been prepared to show the number of replications necessary to make the value two times the standard error of a difference equal to 5% of the general mean of the experiment. This value has been computed for the total yield of each year and for the total yield during the 3 years for each type of plot. In general it appears that the number of replications needed for most types of nursery plots is no greater than the number needed for field plots. However, as stands became thin, the experimental error was greatly increased.

TABLE 3.—*The theoretical number of replications for field plots and nine types of nursery plots necessary to make 5% of the mean equal 2 S.E. diff., 1939–41.*

Type of plot	Standard error of a single determination in percentage of the mean				Number of replications			
	1939	1940	1941	1939–41	1939	1940	1941	1939–41
Field Plots								
1/20 acre	4.38	3.81	8.80	3.87	6.2	4.6	24.8	4.8
Single Rows								
Rows 3 ft. apart	2.87	4.32	10.06	4.76	2.6	6.0	32.4	7.2
Rows 20 in. apart	6.61	7.14	10.01	5.83	14.0	16.3	32.0	10.9
3-Row Plots, 20 Inches Between Rows, 20-Inch Alleys								
Middle rows	4.59	4.06	7.24	4.42	6.7	5.3	16.7	6.2
Three rows	2.64	2.54	4.41	2.07	2.2	2.1	6.2	1.4
3-Row Plots, 12 Inches Between Rows, 20-Inch Alleys								
Middle rows	3.98	6.24	13.58	5.14	5.1	12.5	59.0	8.4
Three rows	3.99	2.80	3.44	2.30	5.1	2.5	3.8	1.7
5-Row Plots, 12 Inches Between Rows, 20-Inch Alleys								
Middle rows	7.27	9.67	15.07	8.11	16.9	29.9	72.6	21.0
Three middle rows	4.91	4.24	8.78	4.67	7.7	5.8	24.7	7.0
Five rows	3.81	4.06	6.19	3.80	4.6	5.3	12.2	4.6

TABLE 4.—*The number of live plants per square meter in the fall of 1941 of five varieties of alfalfa planted in the spring of 1938 in field and nursery plots.*

Varieties	1/20 acre field plots	Nursery plots									Average of all types of plots
		1-row plots 3 feet apart	20-in. rows, 20-in. alleys			12-in. rows, 20-in. alleys					
			1-row plots	3-row plots		3-row plots		5-row plots			
				Middle row	3 rows	Middle row	3 rows	Middle row	3 rows	5 rows	
Hardistan	86	98	124	116	113	151	138	149	149	145	127
Meeker Baltic	14	44	58	44	45	54	45	35	35	31	40
Ladak	37	56	64	69	70	73	60	68	71	64	63
Nebraska Common	15	53	84	66	72	58	57	48	45	42	54
Grimm	14	48	62	48	59	70	71	35	41	36	48
Average	33	60	78	69	72	81	74	67	68	64	66
F values for comparisons of field plots and nursery plots:											
Varieties/varieties × type of plot†	—	23.02**	13.91*	45.12**	20.02**	35.47**	23.39**	21.69**	24.30**	23.40**	—
Varieties × type of plot/error‡	—	3.77*	2.26	1.10	4.16*	1.59	5.52**	7.79**	10.48**	14.85**	—

†D.F., 4 and 4: F for 5% point = 6.39; F for 1% point = 15.98.
‡D.F., 4 and 24: F for 5% point = 2.78; F for 1% point = 4.22.

TABLE 5.—*Agronomic data other than forage yields and stands for five varieties of alfalfa grown in field and nursery plots, 1939–41.*

Varieties	1/20 acre field plots	Nursery plots: 1-row plots, 3 feet apart	Nursery plots: 20-in. rows, 20-in. alleys: 1-row plots	Nursery plots: 20-in. rows, 20-in. alleys: 3-row plots	Nursery plots: 12-in. rows, 20-in. alleys: 3-row plots	Nursery plots: 12-in. rows, 20-in. alleys: 5-row plots	Average of all types of plots
Recovery After First Cutting, 1939–41*							
Hardistan	3.1	4.7	6.0	3.9	4.0	3.8	4.2
Meeker Baltic	4.3	4.6	4.9	3.9	4.6	4.9	4.5
Ladak	9.0	8.9	9.0	9.0	9.0	9.0	9.0
Nebraska Common	3.8	3.5	3.2	2.6	3.1	3.7	3.3
Grimm	4.0	4.6	4.5	3.7	3.8	4.7	4.2
Average	4.8	5.3	5.5	4.6	4.9	5.2	5.0
Recovery After Second Cutting, 1939–41*							
Hardistan	4.1	4.5	4.4	4.3	4.2	4.3	4.3
Meeker Baltic	5.1	4.3	4.5	4.5	4.8	5.1	4.7
Ladak	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Nebraska Common	3.6	2.3	2.5	2.7	2.8	3.6	2.9
Grimm	4.9	4.4	4.1	4.1	4.5	5.0	4.5
Average	5.3	4.9	4.9	4.9	5.1	5.4	5.1
Recovery After Third Cutting, 1939–41*							
Hardistan	5.1	5.0	5.0	5.0	5.0	5.1	5.0
Meeker Baltic	4.4	4.1	4.3	4.5	4.6	4.5	4.4
Ladak	9.0	9.0	9.0	9.0	9.0	8.9	9.0
Nebraska Common	2.4	2.5	2.5	2.4	2.5	2.7	2.5
Grimm	4.3	4.2	4.3	4.3	4.3	4.5	4.3
Average	5.0	5.0	5.0	5.0	5.1	5.1	5.0
Spring Growth, Inches, 1939–41†							
Hardistan	7.7	9.9	8.7	8.9	7.7	8.3	8.5
Meeker Baltic	6.7	9.1	8.1	8.0	7.1	6.9	7.6
Ladak	5.3	7.8	7.3	7.0	5.6	5.7	6.4
Nebraska Common	7.1	9.7	8.1	8.4	8.0	7.5	8.1
Grimm	6.3	8.9	8.5	8.5	7.5	6.7	7.7
Average	6.6	9.1	8.1	8.2	7.2	7.0	7.7
Fall Growth, Inches, Oct. 18, 1940							
Hardistan	4.8	6.6	4.6	4.6	4.2	4.2	4.8
Meeker Baltic	7.0	8.4	6.2	6.8	5.8	6.8	6.8
Ladak	2.2	2.6	2.0	2.0	2.0	2.0	2.1
Nebraska Common	9.6	11.6	8.8	9.2	8.4	9.2	9.5
Grimm	7.0	8.6	6.4	7.0	6.0	6.8	7.0
Average	6.1	7.6	5.6	5.9	5.3	5.8	6.0

TABLE 5.—*Concluded.*

Varieties	1/20 acre field plots	Nursery plots: 1-row plots, 3 feet apart	Nursery plots: 20-in. rows, 20-in. alleys, 1-row plots	Nursery plots: 20-in. rows, 20-in. alleys, 3-row plots	Nursery plots: 12-in. rows, 20-in. alleys, 3-row plots	Nursery plots: 12-in. rows, 20-in. alleys, 5-row plots	Average of all types of plots
Leaf Spot, June 14, 1941‡							
Hardistan	5.0	4.6	5.0	6.2	5.8	5.0	5.3
Meeker Baltic	2.6	3.0	4.2	4.6	4.2	3.8	3.7
Ladak	1.6	3.0	3.8	3.0	3.8	3.8	3.2
Nebraska Common	4.2	4.2	4.2	6.2	6.6	6.6	5.3
Grimm	2.6	4.6	5.8	5.8	6.2	3.8	4.8
Average	3.2	3.9	4.6	5.2	5.3	4.6	4.5
Mildew, June 14, 1941‡							
Hardistan	3.4	2.2	2.2	1.8	2.4	2.2	2.4
Meeker Baltic	1.4	0.8	1.0	1.0	1.0	1.4	1.1
Ladak	1.8	1.2	1.4	1.4	1.4	1.8	1.5
Nebraska Common	1.0	1.8	1.8	2.2	1.8	2.2	1.8
Grimm	1.4	1.0	1.4	1.6	1.0	1.0	1.2
Average	1.8	1.4	1.6	1.6	1.5	1.7	1.6

*1 = rapid; 5 = medium; 9 = slow.
†April 29 in 1939; April 25 in 1940; and May 9 in 1941.
‡0 = none; 1 = little; 5 = medium; 9 = severe.

LONGEVITY OF STANDS

It is likely that the reason for certain types of nursery plots changing in comparability with field plots in yield the last 2 years of the experiment was caused by the thinning of stands as bacterial wilt caused by *Phytomonas insidiosa* killed the plants. During 1938 and 1939 all plots had excellent stands, but by the fall of 1941 the stands of the most susceptible varieties (Meeker Baltic, Grimm, and Nebraska Common) were extremely thin, those of Ladak intermediate, and those of Hardistan quite thick. The data in Table 4 were obtained to determine whether the resistant and susceptible varieties react to wilt relatively the same in nursery plots and field plots. The number of live plants per square meter in the field plots was less than that in any of the nursery plots. The variance analysis shows that the number of live plants of wilt-resistant varieties was relatively not the same in field and nursery plots. Hence, for the determination of the relative wilt resistance of varieties of alfalfa none of the nursery plots herein described is reasonably reliable.

RECOVERY AFTER CUTTING

The varieties of this experiment varied in the rapidity of recovery after cutting (Table 5); Ladak was slowest and Nebraska Common most rapid. The 3 years' data for recovery after the first, second, and

third cuttings show that there was some interaction between ratings for varieties in the different experiments. However, in all instances, these interactions were too small to change the order of decidedly different varieties, such as Nebraska Common and Ladak.

SPRING AND FALL GROWTH

Noticeable differences occurred between the varieties of this experiment in amounts of growth early in the spring and late in the fall (Table 5). Measurements of these characteristics were analyzed statistically to determine the relative performance of varieties in the field plots and in the various types of nursery plots (Table 6). The F values, varieties × types of plots/error, indicate that the varieties in all types of nursery plots, especially the five-row type, had relatively the same degrees of spring and fall growth as in the field plots.

LEAF DISEASES

Occasionally a cutting of hay in this area is severely infected with leaf spot (*Pseudopeziza* spp.), or mildew (*Peronospora trifoliorum*), or both. The first cutting in 1941 showed a considerable amount of both diseases, and differences in amounts of infection on different varieties were noted (Table 5). The data in Table 6 show that the leaf spot readings of some nursery plots correspond well with those of the field plots. The best correspondence with field plots was with the multiple-row nursery plots. The mildew readings for nursery plots were relatively the same as for field plots in four of the five comparisons.

SUMMARY

Five varieties of alfalfa, Hardistan, Meeker Baltic, Ladak, Nebraska Common, and Grimm were seeded in the spring of 1938 at 10 pounds per acre in 1/20 acre field plots and in nursery plots 18 feet long. The types of nursery plots compared with the field plots were as follows: Single rows 3 feet apart and 20 inches apart; three-row plots with rows 20 inches apart and 20-inch alleys, using the middle row and the three rows; three-row plots with rows 12 inches apart and 20-inch alleys, using the middle row and the three rows; and five-row plots with rows 12 inches apart and 20-inch alleys, using the middle row, the three middle rows, and the five rows. The five varieties were replicated five times in Latin square designs in the field and nursery plots. The center 16 feet of the 18-foot nursery rows were harvested for yield. All yields are reported in tons of oven-dry hay an acre.

The data indicate that the first year after seeding several types of nursery plots appeared reliable for predicting field performances of alfalfa varieties. After 3 years of harvesting, the only nursery plots still reliable for predicting field performance of varieties were the middle row, the three middle rows, and the five rows of the five-row plots.

Varietal characteristics such as spring and fall growth and susceptibility to mildew and leaf spots appeared relatively the same in

TABLE 6.—*The F values (varieties/varieties × types of plots) and the F values (varieties × types of plots/error) for agronomic data on five varieties of alfalfa grown in field and nursery plots, 1939–41.*

Field plots compared with	Recovery after			Spring growth, 1939–41	Fall growth, 1940	Leaf spot, 1941	Mildew, 1941
	First cutting, 1939–41	Second cutting, 1939–41	Third cutting, 1939–41				
			Varieties/Varieties × Types of Plots†				
Single rows 3 ft. apart	34**	47**	1,442**	85**	95**	4.14	16.43**
Single rows 20 in. apart	63**	56**	2,947**	7*	303**	1.57	6.56*
Three rows 20 in. apart, 20-in. alleys	47**	76**	3,537**	18**	1,513**	11.39*	3.91
Three rows 12 in. apart, 20-in. alleys	63**	148**	1,590**	15*	140**	5.40	15.21*
Five rows 12 in. apart, 20-in. alleys	139**	1,342**	598**	163**	957**	6.39*	7.47*
			Varieties × Types of Plots/Error‡				
Single rows 3 ft. apart	10.79**	7.85**	0.66	0.65	1.21	1.89	0.40
Single rows 20 in. apart	7.56**	7.80**	0.35	3.02*	0.38	3.98*	0.68
Three rows 20 in. apart, 20-in. alleys	16.06**	7.72**	0.66	2.92*	0.10	0.98	0.94
Three rows 12 in. apart, 20-in. alleys	8.37**	2.73*	1.27	4.29**	0.84	2.04	0.43
Five rows 12 in. apart, 20-in. alleys	3.91**	0.34	2.79*	0.26	0.15	1.30	0.56

†D.F., 4 and 4: F for 5% point = 6.39; F for 1% point = 15.98.
‡D.F., 4 and 72 for 3 years: F for 5% point = 2.50; F for 1% point = 3.59. 4 and 24 for 1 year: F for 5% point = 2.78; F for 1% point = 4.22.

most types of the nursery plots and the field plots. In general the data from nursery plots consisting of five rows 12 inches apart with 20-inch side alleys corresponded most closely to that from the field plots.

The writers recommend the use of the following types of nursery plots for predicting yield and other agronomic characteristics of alfalfa grown under irrigation: (1) Five-row plots with rows 12 inches apart and 20-inch alleys; (2) the three center rows of a five-row plot with rows 12 inches apart and 20-inch alleys; and (3) the middle row of the five-row plots.

The five-row plot is the most practical since it can be handled with machinery and no border rows have to be removed. At least five replications should be used.

A COMPARISON OF SYNTHETIC VARIETIES, MULTIPLE CROSSES, AND DOUBLE CROSSES IN CORN[1]

G. F. SPRAGUE AND MERLE T. JENKINS[2]

MOST of the corn hybrids as now used commercially are double crosses, although single and three-way combinations are used to a limited extent. Relatively little has been done with hybrids involving more than four inbred lines. A knowledge of the performance of such combinations would be of interest from several standpoints. First, it would add to our general knowledge of corn breeding. Their theoretical behavior can be formulated from known genetic principles, but there is little data indicating the agreement between theoretical and actual performance. Second, in some areas outside the Corn Belt considerable difficulty has been experienced in maintaining inbred lines and in producing seed of foundation single crosses. Multiple crosses may be better suited for commercial utilization in these areas than are double crosses. Third, in the course of inbreeding investigations, many inbreds are isolated which possess certain desirable characteristics but because of some specific fault are unsuited for present commercial use in double crosses. Such lines might be of use in crosses involving larger numbers of lines.

For the purpose of this report, a multiple cross is defined as the first generation of a cross containing more than four inbred lines. Either the first generation or the advanced generations of such a combination may be used for commercial corn production. When the advanced generations are grown and the strain is maintained by mass selection, it usually is defined as a synthetic variety. First-generation seed of a multiple cross may be produced by crossing first-generation plants of the two parental hybrids, or by crossing plants of the advanced generations of them. If the two parents of a multiple cross involve as many as 4 to 8 lines each, it may be feasible to maintain them independently as synthetic varieties and produce first-generation hybrid seed of the final multiple combination by crossing the advanced generations of the parental strains.

The theoretical advantages of a multiple cross produced by crossing plants of the advanced generations of its parents are (a) higher yielding ability than synthetic varieties, and (b) less costly foundation seed stocks than for double crosses. Multiple crosses should possess more genetic diversity which should make them less subject to environmental hazards than double crosses. Their theoretical disadvantage lies in the smaller yield expected from a combination involving more than four lines, as compared with the best double cross among the best four of the parental lines.

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[1]Contribution from Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Journal paper J-1041, Project 163. Received for publication September 18, 1942.

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Hayes[3] has reported yields for the F_2 generation of five synthetic varieties. In each case the parental lines were derived from a single variety. When compared with the parental varieties, yields ranged from a decrease of 11.7 to an increase of 16.6%. It should be emphasized that these synthetic varieties were made up in part of lines of unknown productivity.

Yields of the F_1 and F_2 generations of 8 and 16 line synthetics are reported by Kiesselbach.[4] The reduction in yield from the F_1 to the F_2 generations was 5% for the 16-line synthetic and 13 and 9%, respectively, for the 8-line Hogue yellow dent and Nebraska White Prize synthetics. Concerning synthetic varieties in general he states, "The Nebraska Experiment Station has had a number which proved as productive as ordinary varieties but no better".

MATERIAL AND METHODS

Four 16-line and one 24-line synthetic varieties and eight 16-line multiple hybrids have been included in these tests in comparison with from one to five open-pollinated varieties or standard double crosses. The pedigrees of these combinations are given below.

SYNTHETIC VARIETIES

Early.—The following three double-double crosses were produced in 1934:

A = [(Minn. 7 × Minn. 11–28) × (Minn. 11 × Minn. 14)] × [(Wis. R3 × Wis. 3) × (Wis. 6 × Wis. 23)]

B = [(Ia. 153 × Ia. Mc869) × (Ia. GK643 × Ia. GK645)] × [(Wis. 9 × Wis. 25) × (Wis. M13 × Wis. R3)]

C = [(Minn. 374 × Minn. 375) × (Minn. 43 × Minn. 49)] × [(Ia. Cl447 × Ia. Web726) × (Ia. GK645 × Ia. GHL868)]

In 1935 seed of the three possible combinations A × B, A × C, and B × C was produced. Equal quantities of seed of these three combinations were mixed to provide the seed for the F_1 generation of this synthetic.

Stiff.—{[(Ia. I159 × Ia. I224) × (Ia. Os420 × Ia. WD456)] × [(Ind. 461–5 × Ill. I2E) × (CI. 617 × CI. 540)]}

×

{[(Ill. Hy × Oh.3167B) × (Ind. AH83 × Ind. Tr9–1–1–6)] × [(F_1B–1–7–1 × A3G–3–1–3) × (CI.187–2 × LE23)]}

Rough.—{[(Ia. Bl339A × Ia. I233A) × (Ia. Bl351 × Ia. Bl349)] × [(Ind. 461–5 × Ill. I2E) × (Oh.3173D × Ind. B2)]}

×

{[(Ill. R126 × (F_1B)–1–7–1) × (Ill. A × Ia.Bl345)] × [(Oh.3167B × CI.617) × (Ia. Mc401 × Ia.KB397)]}

Smooth.—{[(CI.6–5E × CI.4–8d) × (Ia.L292 × Ia.L289)] × [(Ia.L326 × Ia.L324) × (HDC6166112 × Ia.L337)]}

×

{[(LE23 × KHLE) × (Ill.Hy × CI.187–2)] × [(Ia.L304 × Ia.L325) × (Ia. L317 × CI.623–174)]}

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[3]Hayes, H. K. Present day problems of corn breeding. Jour. Amer. Soc. Agron., 18:344–363. 1926.

[4]Kiesselbach, T. A. The possibilities of modern corn breeding. Proc. World Exhibition and Conf., 2:92–112. 1933.

Low ear.—{[(KHLE × Ill.LE625–S_4) × (MWLE × Ill.LE630–S_4)] × [(Oh.293 × Oh.490K) × (Ind.WF9 × Ind. 66–24)]}
×
{[(Ind.T×B2 × Ind.Tr9122) × (Ill.A × Ill.90)] × [(Ia.Cl447 × Ia. St665) × (CI.4–8 × Ia.B1356)]}

A sufficient quantity of F_1 seed of each combination was produced to plant an isolated plot 1 to 2 acres in size. Two to 5 bushels of sound seed were harvested from these isolated plots, care being exercised to avoid selection for any particular plant or ear characteristic. Similar isolated plots and practices were used to produce seed of the F_3 generation of each strain.[5] The seed of the successive generations of each synthetic used in planting the yield comparisors was produced all in one season by hand pollination. This involved the production of a new supply of F_1 seed and the advancing of previously produced F_1, F_2, and F_3 stocks by sib pollination to the F_2, F_3, and F_4 generations, respectively.

The eight 16-line multiple crosses represent combinations among successive generations of 10 double-double crosses. The pedigrees of these component 8-line foundation strains are as follows:

8022 [(L287 × L304B) × L324 × L326)] × [(L289 × L311) × (L317 × L325)]
8023 [(I159×I224)×(Bl345×Mc401)]×[(I205×Bl351)×(Bl349×WD456)]
8024 [(I159×I224)×(Bl349×Bl351)]×[(Bl345×Mc401)×(Os420×WD456)]
8025 [(I159×I197)×(Bl349×Mc401)]×[(Bl351×Os430)×(Mc415×WD456)]
8026 [(I205×Os420)×(Bl345×Bl349)]×[(Mc401×WD456)×(L×B801)]
8027 [(I159×I268)×(I197×I224)]×[(I198×I244)×(I205×I242)]
8028 [(Bl338×Bl339)×(Bl348×Bl356)]×[(Bl345×Bl349)×(Bl351×Bl352)]
8029 [(Pr364×KB397)×(Os420×Os426)]×[(Mc401×Mc415)×(WD456×ITE 701)]
8030 [(L289×L292)×(L304×L326)]×[(L311×L324)×(L317×L337)]
8031 [(I163×I198)×(I173×I234)]×[(I205×I224)×(I242×I267)]

The 8-line foundation combinations were maintained by sib pollination for three generations. The 16-line hybrids then were produced by crossing plants of the F_1, F_2, F_3, and F_4 generations, respectively, of the parental strains.

Yield comparisons among the four successive generations of the five synthetic varieties were obtained by entering them in the Iowa Corn Yield Test. In 1939 the district tests consisted of five replications of 2 × 12-hill plots. In 1940 they consisted of six replications of 4 × 5-hill plots. In 1941 they consisted of nine replications of 2 × 10-hill plots.

The yield comparisons involving the multiple crosses were made at Ames, Iowa. Plantings were grown in four replications of 2 × 10-hill plots in each of the 3 years, 1939–41, inclusive.

EXPERIMENTAL RESULTS

SYNTHETIC VARIETIES

The theoretical reductions in yield to be expected from advanced generations of a synthetic variety can be calculated from the formula

[5]The Early Synthetic was advanced in this manner by R. R. St. John in Illinois; the Stiff Stalked Synthetic and the Rough Synthetic by A. A. Bryan in Iowa; the Smooth Synthetic by R. D. Lewis in Ohio; and the Low Ear Synthetic by A. A. Bryan and G. F. Sprague in Iowa.

$\frac{1}{n}$ (hybrid-inbred), where n is the number of lines involved and "hybrid" refers to the average performance of all the possible single-cross combinations among the parental lines involved and "inbred" refers to the average performance of the inbred lines themselves. Four factors operate in determining the yield of the advanced generations of synthetic varieties. These are (a) the number of lines involved, (b) the mean yield of these lines, (c) the mean yield of all of their possible single crosses, and (d) the percentage of self pollination. This latter factor is of limited importance in corn because of almost universal cross pollination under natural conditions. It may be of great importance, however, if this breeding method is applied to other crops.

The lines involved in the synthetic varieties included in these tests, as their designations imply, were chosen because of specific characteristics. Little attention was paid to their combining ability. The data from the yield comparisons are presented in Table 1.

TABLE 1.—*Acre yields in bushels for four generations of each of five synthetic varieties included in the Iowa Corn Yield Test.*

Year	District	Acre yield in bushels				Average advanced generations	Av. open-pollinated varieties
		F_1	F_2	F_3	F_4		
				Early			
1939	1	63.00	66.41	67.05	58.71		75.68
	2	59.81	60.07	64.30	58.79		69.65
	3	53.06	52.63	52.91	56.51		55.66
	Northern Section	58.62	59.70	61.42	58.00	59.71	67.00
				Stiff			
1939	7	73.67	70.59	72.36	71.61		65.45
	8	79.24	69.56	66.48	82.21		72.91
	9	94.70	82.07	90.22	87.73		85.42
	S. C. Section	82.54	74.07	76.35	80.52	76.98	74.59
				Rough			
1940	10	58.74	64.77	58.60	65.04		56.12
	12	82.73	76.71	71.79	64.54		77.26
	Southern Section	70.74	70.74	65.20	64.79	66.91	64.92
				Smooth			
1940	10	62.43	51.37	54.25	52.16		56.12
	12	79.54	72.55	73.43	74.33		77.26
	Southern Section	70.99	61.96	63.84	63.25	63.02	64.92
				Low Ear			
1941	7	61.86	57.24	58.95	56.97		60.95
	8	59.66	58.28	59.68	55.74		73.12
	9	69.10	63.90	66.36	69.19		78.54
	S. C. Section	63.54	59.81	61.66	60.63	60.70	70.87
Av. % of F_1 generation		100.0	94.27	95.41	95.10		

The yield of the four successive generations of the synthetic varieties varied considerably within the individual district tests. These differences in yield were not consistent, suggesting that most of the variation was random. When the average yields of all synthetics over all generations are compared, the F_1 generation yielded most and the F_2, F_3, and F_4 generations are quite similar in yield. This behavior is expected on theoretical grounds.

With the exception of the early and the low-ear synthetics, the average yield for the advanced generations closely approximate the average yield of the open-pollinated varieties entered in the tests. The "early" synthetic was considerably earlier than the varieties with which it was compared. This probably accounts in part for its lower yield. In the 1941 tests involving the low-ear synthetic, only a single open-pollinated variety was available for comparison. For comparisons in other years averages of at least five varieties were available.

If these synthetics are considered as typical, it would seem that their practical possibilities are limited. However, it is the feeling of the writers that considerably higher yielding combinations than these could be prepared. With a large number of lines from which to select, it would appear to be entirely feasible to produce combinations which will exceed open-pollinated varieties in general performance. However, where adapted double-cross hybrids are available the time and labor required to produce and test new synthetic varieties could better be expended in other channels.

MULTIPLE HYBRIDS

Multiple hybrids better utilize hybrid vigor than do synthetic varieties. Their yields, therefore, should be more comparable to those obtained from good double crosses. The foundation strains may be maintained under conditions of adequate isolation and the final multiple hybrids made between advanced generation stocks of them. The crosses so produced should be equal in yielding ability to the hybrids made between their F_1 generations. Contamination, inadequate sampling, and natural or artificial selection in the parental strains, however, could modify the performance of the hybrids between advanced generations of them.

Each of ten 8-line foundation stocks involved in the 16-line multiple crosses tested were produced by combining related material in order to insure the maximum yield in the final hybrid. For example, 8022 and 8030 contain only lines from Lancaster Surecrop, 8027 and 8031 lines from Iodent, and 8028 lines from the Black strain of Reid Yellow Dent. The other combinations are somewhat more varied in their inheritance, the individual lines representing two or more strains of Reid Yellow Dent.

Yield data were obtained on the F_1 generation of the parent stocks in 1935. The data are presented in Table 2. Yields are somewhat lower, in general, than for the standard double crosses Iowa 939 and Iowa 13. This would be expected on the basis of the close relationship of the component lines.

TABLE 2.—*Acre yields in bushels for the F_1 generation of ten 8-line foundation stocks used as parents of eight 16-line multiple crosses and of two commercial double crosses, Ames, Iowa, in 1935.*

Hybrid	Acre yield bu.	Moisture content, %	Lodging grade		Damaged kernels, %	Broken shanks, %
			Root	Stalk		
Iowa 939	79.1	22.4	1.3	1.2	6.7	4.0
Iowa 13	78.3	25.7	2.5	1.2	7.5	0.9
8022	66.9	27.8	2.2	1.7	7.9	0.9
8023	73.8	26.8	1.5	1.0	7.8	1.4
8024	72.5	24.1	1.5	1.0	7.5	1.0
8025	68.3	24.7	1.5	1.0	12.4	0.0
8026	69.7	25.8	1.2	1.2	9.0	0.0
8027	60.2	23.2	1.3	1.2	11.5	0.6
8028	68.1	26.9	1.8	1.3	8.6	0.9
8029	73.3	26.5	1.2	1.2	4.3	0.6
8030	78.5	29.7	3.2	2.2	10.5	0.6
8031	72.5	23.3	2.3	1.7	5.0	0.0

Seed of the F_2, F_3, and F_4 generations of each of the 8-line combinations was obtained by sib-pollination. Then eight 16-line hybrids were produced by crossing plants of the F_1, F_2, F_3, and F_4 generations, respectively. In every case the crosses were made so that the two 8-line combinations comprising the various final hybrids were entirely unrelated. Yield comparisons were made over a 3-year period, 1939–41, inclusive. The field design was of the split-plot type, the split being on the four generations. This gives fair precision on the differences among multiple crosses and greater precision on generations and the multiple × generation interaction. Average acre yields in bushels of the four entries of each multiple cross (the entries produced by crossing parental plants of the F_1, F_2, F_3, and F_4 generations, respectively) for each of the 3 years, 1939–41, are presented in Table 3.

In 1939 and 1941 the best multiple crosses yielded substantially higher than the average of the standard double crosses. In 1940 the average yield of the standard double crosses was 3.1 bushels higher than the highest yielding multiple cross. Thus, from the standpoint of yield the multiple crosses compare quite favorably with standard double crosses now in commercial use.

In 1939 the variance associated with the differences among multiple crosses, generations, and the strain × generation interaction were all highly significant. No significant differences would be expected among generations except through changes in gene frequency brought about by selection or inadequate sampling. In six of the eight multiple crosses, the crosses involving the F_3 and F_4 generations of the foundation stocks were higher yielding than the corresponding hybrids involving the F_1 or F_2 generations.

In 1940 the variance associated with the differences among multiple crosses was significant at the 5% level. The differences among generations and the strain × generation interaction were highly significant. In this year, also, the crosses between the F_3 and F_4 generations of

TABLE 3.—*Acre yields in bushels for four standard double crosses and eight 16-line multiple crosses for the 3-year period, 1939–41, inclusive.*

Hybrid No.	Yield in bushels per acre			
	1939	1940	1941	Average
		Double Cross		
3020	99.6	95.2	77.2	90.7
3110	115.2	100.1	83.8	99.7
3342	99.5	107.3	82.8	96.5
U. S. 44	95.5	90.4	85.7	90.5
Average	102.5	98.3	82.4	94.4
		Multiple Cross		
8806 (8022 × 8023)	113.7	90.4	88.3	97.5
8807 (8022 × 8024)	108.4	95.2	77.0	93.5
8808 (8022 × 8025)	103.5	91.9	85.9	93.7
8809 (8022 × 8026)	103.7	84.6	79.7	89.3
8810 (8028 × 8030)	107.4	90.8	84.8	94.3
8811 (8029 × 8030)	97.9	88.7	73.5	86.7
8812 (8030 × 8031)	99.6	93.0	66.9	86.5
8813 (8022 × 8027)	103.1	91.0	65.3	86.4

the foundation stocks were consistently higher in yield than comparable crosses involving the F_1 and F_2 generations.

The 1941 yield trials were somewhat less accurate than for the previous two seasons due to damage by standing water in early summer. As a result the error variance was high. The variance associated with the differences among strains was highly significant, whereas the variance associated with generations was not significant. The strain × generation interaction was significant at the 5% level.

The summarized agronomic data for the 3-year period are presented in Table 4. It was thought inadvisable to use the analysis of variance for the pooled data, due to the marked differences in variability from year to year. It will be noted that the most serious limitation of this group of multiple crosses is their susceptibility to lodging. This weakness arises, however, from the lines involved rather than from any inherent limitations of this breeding method. Greater lodging resistance in the parental lines would correct this defect.

Hybrids produced between plants of the F_3 and F_4 generations, respectively, of the foundation stocks were more productive in each of the 3 years of test than the corresponding hybrids produced between plants of the F_1 and F_2 generations. Any change in genetic composition of these foundation stocks arising through sampling or selection should be cumulative. In each of the 3 years, the same general trend is evident. The data are presented in graphic form in Fig. 1. As the seed for all three tests came from the seed lots produced in 1938, the year-to-year fluctuation must be in part due to environmental response. Furthermore, in each of the 3 years the strain × generation interaction was significant indicating that the generation effect was not the same in all hybrids. Limited sampling appears

TABLE 4.—*Summary of data recorded on F_1, F_2, F_3, and F_4 generation hybrids of eight 16-line synthetics and four commercial hybrids grown at Ames, Iowa, for the 3-year period, 1939–41, inclusive.*

Cross No.	Pedigree	Acre yield, bu.	Moisture, %	Lodging, %		Smut, %	Dropped ear, %	Ear height, grade	Stand, %
				Root	Stalk				
	Double Crosses								
3020	(L317 × Bl349) × (Bl345 × Mc401)	90.7	17.4	3.7	17.0	0.9	1.3	3.7	97.4
3110	(I159 × I224) × (L289 × L317)	99.7	19.1	1.2	16.9	1.5	1.0	4.0	98.1
3342	(L317 × ITE701) × (Bl345 × Mc401)	96.5	17.0	5.4	21.4	0.0	0.7	4.0	97.0
U. S. 44	(187-2 × 4-8) × (Hy × 540)	90.5	17.1	1.1	6.7	0.2	0.3	3.2	97.8
	Mean	94.4	17.7	2.9	15.5	0.7	0.8	3.7	97.6
	Multiple Crosses								
8806	($8002F_1$ × $8023F_1$)	94.7	16.4	5.1	15.9	1.5	3.4	3.3	96.1
	($8002F_2$ × $8023F_2$)	90.2	18.4	4.7	16.3	1.3	3.0	2.9	95.0
	($8002F_3$ × $8023F_3$)	103.4	18.0	3.7	16.9	0.4	2.9	3.3	95.8
	($8002F_4$ × $8023F_4$)	101.6	18.6	3.3	14.3	0.6	2.5	3.5	98.0
	Mean	97.5	17.9	4.2	15.9	1.0	3.0	3.3	96.2
8807	(8022 F_1 × 8024 F_1)	89.7	17.9	3.4	25.8	1.5	3.3	3.4	96.3
	(8022 F_2 × 8024 F_2)	88.9	17.0	6.6	17.1	1.7	2.7	3.3	94.6
	(8022 F_3 × 8024 F_3)	94.9	18.5	6.8	19.2	1.3	2.0	3.4	94.9
	(8022 F_4 × 8024 F_4)	100.6	17.5	4.0	19.3	1.5	2.6	3.3	96.2
	Mean	93.5	17.7	5.2	20.4	1.5	2.7	3.4	95.5
8808	(8022 F_1 × 8025 F_1)	87.8	18.1	3.4	21.7	1.5	1.7	3.4	96.7
	(8022 F_2 × 8025 F_2)	90.3	18.7	4.9	15.3	1.3	1.6	3.3	97.8
	(8022 F_3 × 8025 F_3)	94.9	19.9	6.0	19.6	2.3	1.3	3.5	95.1
	(8022 F_4 × 8025 F_4)	101.9	20.0	7.8	20.1	1.5	1.0	3.6	97.9
	Mean	93.7	19.2	5.5	19.2	1.7	1.4	3.5	96.9

8809	(8022 F_1 × 8026 F_1)	87.3	17.0	7.3	17.7	1.3	2.1	3.1	94.0
	(8022 F_2 × 8026 F_2)	90.6	17.9	7.1	14.8	2.1	2.1	3.2	96.7
	(8022 F_3 × 8026 F_3)	92.1	19.2	8.9	17.5	0.6	1.7	3.1	97.5
	(8022 F_4 × 8026 F_4)	87.1	17.8	3.0	17.6	0.9	1.3	3.1	92.8
	Mean	89.3	18.0	6.6	16.9	1.2	1.8	3.1	95.3
8810	(8028 F_1 × 8030 F_1)	92.7	18.3	15.5	24.6	1.3	2.2	3.3	95.2
	(8028 F_2 × 8030 F_2)	95.7	19.8	16.9	23.2	3.2	1.3	3.4	95.5
	(8028 F_3 × 8030 F_3)	96.3	18.2	13.0	21.3	2.1	2.7	3.8	96.1
	(8028 F_4 × 8030 F_4)	92.5	17.2	9.8	18.2	3.0	1.8	3.8	95.1
	Mean	94.3	18.4	13.8	21.8	2.4	2.0	3.6	95.5
8811	(8029 F_1 × 8030 F_1)	88.3	19.5	7.7	21.7	1.3	1.4	3.4	97.2
	(8029 F_2 × 8030 F_2)	85.6	17.7	8.9	20.3	0.9	2.4	3.5	95.9
	(8029 F_3 × 8030 F_3)	88.9	19.0	5.6	26.1	1.7	2.7	3.7	96.0
	(8029 F_4 × 8030 F_4)	84.0	18.9	3.9	21.6	2.1	1.1	3.2	96.6
	Mean	86.7	18.8	6.5	22.4	1.5	1.9	3.5	96.4
8812	(8030 F_1 × 8031 F_1)	87.4	18.8	15.4	27.4	2.1	1.7	3.3	95.6
	(8030 F_2 × 8031 F_2)	90.7	19.0	9.9	23.8	1.9	1.1	3.9	96.7
	(8030 F_3 × 8031 F_3)	87.1	18.5	11.4	28.7	1.3	1.0	3.6	94.3
	(8030 F_4 × 8031 F_4).	80.7	17.7	9.2	31.8	1.1	2.0	3.8	94.3
	Mean	86.5	18.5	11.5	27.9	1.6	1.5	3.7	95.2
8813	(8022 F_1 × 8027 F_1)	84.4	18.3	8.3	22.3	1.9	3.1	3.3	94.4
	(8022 F_2 × 8027 F_2)	84.6	18.6	11.9	15.9	1.9	2.0	3.1	94.4
	(8022 F_3 × 8027 F_3)	90.4	18.9	6.5	15.7	1.8	3.1	3.2	92.5
	(8022 F_4 × 8027 F_4)	86.3	17.8	6.6	20.9	2.9	1.1	3.4	95.6
	Mean	86.4	18.4	8.3	18.7	2.1	2.3	3.3	94.2
	$F_1 \times F_1$	89.0	18.0	8.3	22.1	1.6	2.4	3.3	95.7
	$F_2 \times F_2$	89.6	18.4	8.9	18.3	1.8	2.0	3.3	95.8
	$F_3 \times F_3$	93.5	18.8	7.7	20.6	1.4	2.2	3.5	95.3
	$F_4 \times F_4$	91.8	18.2	6.0	20.5	1.7	1.7	3.5	95.8

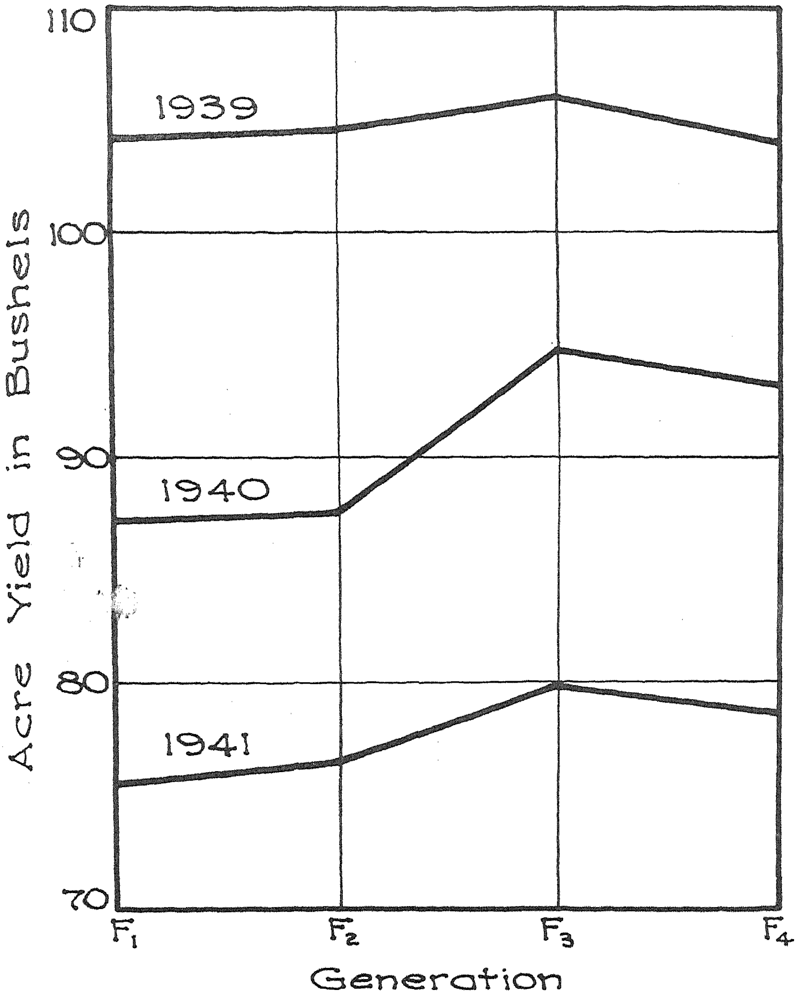

FIG. 1.—Average acre yield in bushels for crosses between the F_1, F_2, F_3, and F_4 generations of 8-line synthetic stocks.

to offer the most logical explanation of these facts. The production of the advanced generation foundation stocks was done by controlled sib pollination in paired rows. On an average about 30 plants were sampled in each generation in continuing the foundation stocks. A certain amount of selective elimination of the later and weaker plants would inevitably result from this procedure. The amount of such elimination might be expected to vary somewhat from culture to culture. Whether this elimination is the sole factor responsible for the yield differences obtained cannot be determined from the data at hand.

DISCUSSION

All data on synthetic varieties so far reported indicate that it is not easy to produce combinations yielding materially more than adapted open-pollinated varieties. Theoretically, it is possible to produce them, given a large enough number of lines with high average combining ability. The labor required to produce and test such varieties, however, can be expended more advantageously in other breeding technics.

Synthetic varieties seem to have their greatest field of usefulness as temporary substitutes in areas where adapted double crosses are not yet available and as convenient reservoirs of desirable gene combinations. The Stiff Synthetic is an example of such use. A rather large number of inbred lines have been extracted from this synthetic and subjected to preliminary testing in hybrid combinations. They have been outstanding in their performance as a group, both in yield and in resistance to lodging.

The data presented here indicate that multiple crosses can be produced which are fully as productive as the standard double crosses now available. Furthermore, seed costs should be somewhat lower than for the double crosses. It should be pointed out, however, that the yield of such multiple crosses is merely the average of all of the possible hybrid combinations among the lines contributed by one parent and those contributed by the other parent. Some of these specific combinations are certain to be materially higher in performance than the average. Where the use of double crosses is feasible, it should be more efficient and economical to locate and make use of these desirable high-yielding combinations in double crosses than to use multiple crosses.

It has been suggested that, under conditions where midsummer droughts are frequent, the yields of extremely uniform hybrids may be materially reduced. While there is no proof that uniformity is a real handicap, several hybrid corn companies are now offering hybrid blends (mixtures of two or more double crosses of slightly different maturity) and recommending that these be grown under adverse conditions. If there is a real advantage in such genetic variability, multiple crosses should prove desirable as they are considerably more variable than double crosses. Their usefulness cannot be predicted but must necessarily depend upon their performance under actual farm conditions.

SUMMARY

Data are presented on the performance of five synthetic varieties and 16-line multiple crosses produced by crossing plants of the F_1, F_2, F_3, and F_4 generations, respectively, of their 8-line foundation strains.

Synthetic varieties have given approximately the same yield performance as adapted open-pollinated varieties. Their greatest usefulness may be as reservoirs of desirable gene combinations.

Multiple crosses compare favorably in yield with the standard double crosses now available. They may have real possibilities under adverse conditions where seed costs and variability in the crop are items of considerable importance.

A STATISTICAL ANALYSIS OF VARIETAL YIELDS OF SUGARCANE OBTAINED OVER A PERIOD OF YEARS[1]

GEORGE ARCENEAUX AND L. P. HEBERT[2]

THE experimental error derived from the results of a varietal yield test at one locality in a single year, while essential in the interpretation of the underlying data, sheds little light on some of the more fundamental aspects of varietal evaluation. For an adequate appraisal of the relative merits of a group of varieties it is of course necessary to take into consideration the differential response of the varieties to differences in environmental conditions within the area in which they are to be utilized, but above all it is important to know something about the differential effect of variations in weather or other conditions experienced from year to year.

In testing the adaptability of a given group of varieties it is customary to conduct similar tests simultaneously, at a number of stations. By combining results of such a series of tests it is possible, through the use of methods of statistical technic developed by Fisher (4)[3] and others, to measure differential response, if any, between the different varieties at the various stations. If such a series of tests is continued over a period of years, it is likewise possible to measure possible differential response between the different varieties as related to differences between years.

DATA

Fig. 1 and the appended statistical summary illustrate results of a typical sugarcane variety test as conducted by the U. S. Dept. of Agriculture in Louisiana. Table 1 gives first-stubble results of such tests with the same group of varieties at each of four stations over a period of 4 years with a statistical analysis of the data. Each of the 16 experiments was conducted on a separate set of plots with a different randomization from every other set. According to Bartlett's test (7) the error variances may be considered homogeneous (chi square = 14.95; P = approximately .46) and thus the 16 individual error terms, each based on 20 degrees of freedom, may be combined, giving a sum square of 1501.89 for a total of 320 degrees of freedom. The effect of varieties and the interactions of variety × station, variety × year, and variety × station × year are all highly significant as indicated by F values (8).

[1]Contribution from the Division of Sugar Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication October 13, 1942.

[2]Agronomist and Junior Agronomist, respectively. Some of the tests covered by this report were conducted by I. E. Stokes, Division of Sugar Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, and some by R. T. Gibbens, Jr., formerly of this Division. The authors are indebted to Roy A. Chapman, Forestry Service, U. S. Dept. of Agriculture, W. G. Cochran, Iowa State College, and F. R. Immer, University of Minnesota, for helpful suggestions in connection with statistical calculations.

[3]Figures in parenthesis refer to "Literature Cited", p. 159.

							Row totals
	37.8 (C. P. 28/11)	36.6 (C. P. 29/320)	26.6 (Co. 281)	49.1 (C. P. 29/116)	32.0 (C. P. 28/19)	49.3 (Co. 290)	231.4
	32.8 (C. P. 28/19)	25.0 (Co. 281)	49.1 (Co. 290)	36.3 (C. P. 29/320)	38.4 (C. P. 28/11)	51.4 (C. P. 29/116)	233.0
	51.8 (Co. 290)	36.2 (C. P. 28/11)	47.6 (C. P. 29/116)	25.8 (Co. 281)	35.0 (C. P. 29/320)	34.6 (C. P. 28/19)	231.0
	31.6 (C. P. 29/320)	44.0 (Co. 290)	25.7 (C. P. 28/19)	37.4 (C. P. 28/11)	45.5 (C. P. 29/116)	26.6 (Co. 281)	210.8
	54.6 (C. P. 29/116)	32.5 (C. P. 28/19)	36.0 (C. P. 28/11)	50.4 (Co. 290)	28.0 (Co. 281)	39.9 (C. P. 29/320)	241.4
	25.2 (Co. 281)	47.0 (C. P. 29/116)	33.6 (C. P. 29/320)	33.2 (C. P. 28/19)	51.8 (Co. 290)	37.4 (C. P. 28/11)	228.2 Grand total
Column totals	233.8	221.3	218.6	232.2	230.7	239.2	1375.8

Variety totals		Analysis of variance				
		Source	Degrees of freedom	Sum of squares	Mean square	F
Co. 281	157.2	Rows	5	85.14	17.03	5.69**
Co. 290	296.4	Columns	5	51.19	10.24	3.42**
C. P. 28/11	223.2	Varieties	5	2638.13	527.63	176.35**
C. P. 28/19	190.8	Error	20	59.85	2.992	
C. P. 29/116	295.2	Total	35	2834.31		
C. P. 29/320	213.0					
Total	1375.8					

FIG. 1.—Plot arrangement and statistical analysis of yields in tons of cane per acre obtained in a typical sugarcane variety test as conducted in Louisiana. Variety designations shown in parenthesis.

The effects of rows, columns, and their interactions are of no essential importance in the interpretation of the results and hence may be omitted from the general analysis. It is interesting to note, however, that in the case cited as an illustration, the Latin square design has resulted in significantly improved accuracy. This has been quite generally true under southern Louisiana conditions (3).

It will be noted that the total yields of individual varieties ranged from 2,056.8 to 3,724.2 tons per acre. The standard error of a total of 96 plots on the basis of the generalized error is $2.1663\sqrt{96}$ or ± 21.23. The standard error of the difference is therefore $\pm 21.23\sqrt{2}$ or

TABLE 1.—*Summation of varietal yields of cane in tons per acre (totals of six plots) in tests at four stations during 1937–40, inclusive.**

Year	Yield of cane per acre, tons							
	Co. 281	Co. 290	CP 28/11	CP 28/19	CP 29/116	CP 29/320	Six varieties	Error S.S. (D.F. = 20)
Raceland Station								
1937	136.8	213.6	163.2	168.6	176.4	162.6	1,021.2	177.76
1938	175.8	247.8	186.6	210.6	241.2	207.0	1,269.0	90.64
1939	163.8	229.8	177.6	195.0	252.6	197.4	1,216.2	89.00
1940	112.8	169.2	114.6	137.4	181.2	133.2	848.4	84.36
Total.	589.2	860.4	642.0	711.6	851.4	700.2	4,354.8	—
Albania Station								
1937	129.6	239.4	160.2	177.0	201.0	197.4	1,104.6	92.48
1938	72.0	225.6	164.4	141.6	214.8	133.2	951.6	49.04
1939	118.2	217.2	130.2	129.0	204.0	162.0	960.6	67.24
1940	76.2	147.0	109.2	87.6	178.2	108.0	706.2	108.12
Total.	396.0	829.2	564.0	535.2	798.0	600.6	3,723.0	—
Rosewood Station								
1937	145.8	218.4	172.8	168.0	284.2	183.0	1,172.2	116.16
1938	141.6	222.0	181.8	172.8	266.4	203.4	1,188.0	64.44
1939	126.0	190.2	153.0	134.4	221.0	159.6	984.2	87.48
1940	115.8	196.2	161.4	111.6	255.0	133.2	973.2	95.12
Total.	529.2	826.8	669.0	586.8	1,026.6	679.2	4,317.6	—

Alma Station

1937	138.0	255.0	192.6	140.4	247.2	200.4	1,173.6	114.68
1938	157.2	296.4	223.2	190.8	295.2	213.0	1,375.8	59.85
1939	161.4	287.4	210.6	176.4	321.0	214.2	1,371.0	79.04
1940	85.8	146.4	160.8	112.2	184.8	86.4	776.4	126.48
Total	542.4	985.2	787.2	619.8	1,048.2	714.0	4,696.8	—
4 years at 4 stations	2,056.8	3,501.6	2,662.2	2,453.4	3,724.2	2,694.0	17,092.2	—

Analysis of Variance

Source	Degrees of freedom	Sum of squares	Mean square	S.E.	F
Varieties	5	21,196.46	4,239.292	—	903.32**
Stations	3	3,408.23	—	—	—
Year	3	9,073.78	—	—	—
Int. station × year	9	4,020.73	—	—	—
Int. variety × station	15	2,182.55	145.503	12.0625	31.00**
Int. variety × year	15	902.04	60.136	7.7547	12.81**
Int. variety × station × year	45	1,716.72	38.149	—	8.13**
Error	320	1,501.89	4.693	2.1663	—

*See Fig. 1 for illustration.

±30.02. This number multiplied by appropriate t values gives the differences of 59.1 and 77.8, corresponding to probability levels of .05 and .01, respectively. At each of these two levels, 14 of the 15 differences obtained by comparing the six varieties may be regarded as significant.

If, on the other hand, we take the observed variance due to interaction of variety × year as a basis for measuring varietal superiority *during all years*, only 12 and 11 differences, respectively, would be significant at the two above-mentioned levels of probability. Finally, if we use interaction of variety × locality variance as a measure of varietal superiority at all stations, still fewer differences can be considered significant.

Table 3 gives variety × station interaction terms, calculated from summation values given in Table 2 as illustrated in the footnote to Table 3. The sum of such values for any given locality or for any given variety will be zero. (Slight departure in totals of values given in the table are due to rounding off to nearest decimal). Departure from zero of individual interaction terms as well as that of their cross differences may be taken as a measure of differential response. The statistical interpretation of such data has been illustrated by Immer, *et al.* (5).

TABLE 2.—*Total yield in tons per acre of 24 plots of each variety at each of four stations during 1937–40, inclusive.**

Variety	Stations					
	Raceland	Albania	Rose-wood	Alma	Total	Mean
Co. 281.......	589.2	396.0	529.2	542.4	2,056.8	514.2
Co. 290.......	860.4	829.2	826.8	985.2	3,501.6	875.4
C. P. 28/11....	642.0	564.0	669.0	787.2	2,662.2	665.5
C. P. 28/19....	711.6	535.2	586.8	619.8	2,453.4	613.3
C. P. 29/116...	851.4	798.0	1,026.6	1,048.2	3,724.2	931.0
C. P. 29/320...	700.2	600.6	679.2	714.0	2,694.0	673.5
Total.........	4,354.8	3,723.0	4,317.6	4,696.8	17,092.2	—
Mean.........	725.8	620.5	719.6	782.8	—	712.2

*Summary of Table 1.

It will be noted that each value given in Table 3 is derived from values given in Table 2 in the following manner: Observed value plus general mean minus row mean, minus column mean. The calculation of the standard deviation of such a term is complicated by the fact that the four underlying values mentioned above are not independent. Such a term may, however, be readily resolved to the basis of independent values from which a valid estimate of the standard deviation can be made. It may be shown that the standard deviation of a value given in Table 3 equals $\sigma\sqrt{k}\sqrt{\frac{(m-1)(n-1)}{mn}}$, in which $\sigma = 2.1663$; $k = 24$; $m = 6$; $n = 4$. This is calculated to be

TABLE 3.—*Individual values for variety × station interaction.**

Variety	Raceland	Albania	Rosewood	Alma
Co. 281	61.4	−26.5	7.6	−42.4
Co. 290	−28.6	45.5	−56.0	39.2
C. P. 28/11	−37.1	− 9.8	− 3.9	51.1
C. P. 28/19	84.7	13.6	−33.9	−64.1
C. P. 29/116	−93.2	−41.3	88.2	46.6
C. P. 29/320	13.1	18.8	− 1.7	−30.1

	Standard deviation	Value for P	
		0.05	0.01
Single values	8.39	16.51	21.74
Difference between values for different varieties at the same station	13.00	25.58	33.68
Difference between values for the same variety at different stations	13.70	26.96	35.50

*From summation given in Table 2, e.g., value for Co. 281 at Raceland = 589.2 + 712.2 − 514.2 − 725.8 = 61.4.

±8.39. The standard deviation of the difference between interaction values for different varieties at the same station is calculated to be $\sigma\sqrt{k}\sqrt{\frac{2(n-1)}{n}} = \pm 13.00$ and the difference between values for the same variety at different stations, $\sigma\sqrt{k}\sqrt{\frac{2(m-1)}{m}} = \pm 13.70$. Values corresponding to two levels of statistical significance as shown in Table 3 were calculated from above given standard deviations and appropriate t values.

Data given in Table 3 show that the relative yields of the varieties have been quite different from station to station. For instance the performance of C.P. 28/19 was relatively good and that of C.P. 29/116 relatively poor at Raceland, while the opposite was true at Rosewood. Numerous other contrasting yield trends between stations could be cited. Some of these, for instance the differential performance of Co. 281 and Co. 290 as between areas represented by Albania and Raceland, respectively, has already been clearly recognized by the industry.

Values for variety × year interaction given in Table 4 and their statistical significance were determined according to the method described in connection with the analysis of variety × station interaction discussed above. These indicate a rather pronounced differential response from year to year. It will be noted further that, quite aside from the random fluctuations in relative varietal yield which would normally be expected, values calculated for some of the varieties have tended to *increase* from year to year while an opposite trend has been maintained in the case of other varieties. For instance,

the change in relative performance of C.P. 29/116 tended rather consistently in a positive direction while the opposite was true with Co. 290. By taking varietal interaction value given in Table 4 as the dependent and year as the independent variable it is possible to arrive at a measure of the linear regression and its significance in each case.

TABLE 4.—*Individual values for variety × year interaction.**

Variety	Year 1937 Y_1	1938 Y_2	1939 Y_3	1940 Y_4	Linear regression of interaction value on year $(3Y_4 + Y_3 - Y_2 - 3Y_1)$
Co. 281	2.9	−52.8	12.1	37.9	169.9
Co. 290	17.9	31.2	6.1	−55.1	−244.1
C. P. 28/11	− 9.8	5.3	−37.2	42.0	112.9
C. P. 28/19	7.6	17.3	−21.6	− 3.0	− 70.7
C. P. 29/116	−55.3	1.4	24.5	29.7	278.1
C. P. 29/320	36.8	− 2.1	16.6	−51.2	−245.3

	Standard deviation	Value for P 0.05	0.01
Interaction values	8.39	16.51	21.74
Difference between interaction values for different varieties during same year	13.00	25.58	33.68
Difference between interaction values for the same variety during different years	13.70	26.96	35.50
Linear regression of interaction value on year	43.33	85.27	112.27

*Total of all stations, Table 1.

The linear regression may be measured by use of the formula $3Y_4+Y_3-Y_2-3Y_1$ (6), in which Y_1 will be the interaction value given for the particular variety for 1937; Y_2 the value for the same variety for 1938, etc. For instance, linear regression of C.P. 29/116 on year = $3(29.7) + 24.5 - 1.4 - 3(-55.3) = 278.1$. It can be shown that the standard deviation of such a regression value may be estimated as $\sigma\sqrt{\bar{k}}\sqrt{\frac{20(m-1)}{m}} = 43.33$. (Values of σ, k, and m are the same as previously given. These and the term 20 are derived from a simplication of the formula for the standard deviation of $3Y_4 + Y_3 - Y_2 - 3Y_1$ expressed in terms of independent values.) Values corresponding to the two levels of statistical significance given in Table 4 were determined in the usual way. The linear regression values for the varieties C.P. 29/116, Co. 281, and C.P. 28/11 are significantly positive, while those for Co. 290 and C.P. 29/320 are significantly negative.

By referring to Table 1 it will be noted that the variance of the interaction of variety × station × year is significantly greater

than the error variance. This indicates that possibly additional information with respect to the differential performance of varieties from year to year could be extracted from the data by a study of varietal trends maintained at each of the four stations.

The component of the variance due to the interaction of variety $\times$ year $\times$ station based on 45 degrees of freedom and that due to the interaction of variety $\times$ year based on 15 degrees of freedom may be combined and then broken up into the interaction of variety $\times$ year at each of the four stations as follows:

Station	Interaction, variety $\times$ year			
	Degrees of freedom	Sum of squares	Mean square	F
Raceland	15	264.28	17.619	3.75
Albania	15	877.84	58.523	12.47
Rosewood	15	402.57	26.838	5.72
Alma	15	1074.07	71.605	15.26
Error	320	1501.89	4.693	——

It will be noted that the variance of the interaction of variety $\times$ year observed at each station is significantly greater than the generalized error variance.

Individual values for variety $\times$ year interaction as observed at each of the four stations are given in Table 5. The method of calculation was the same as employed for determining values given in Table 3.

Table 6 gives the linear regression of varietal interaction term on year for each variety at each station as based on data given in Table 5. The formula for estimating the standard deviation of such a regression value as calculated in the manner indicated earlier in this paper is $\sigma\sqrt{k'}\sqrt{\frac{20(m-1)}{m}}$ with values of σ and m as previously given and that of $k' = 6$. (Unit values consist of six-plot totals).

It will be noted that at one extreme of the group we find C.P. 29/116 showing a significantly positive regression value at each of two stations and insignificantly positive values at the other two. At the other extreme we find C.P. 29/320 with a significantly negative regression value at each of two stations and insignificantly negative values at the other two. Co. 281, like C.P. 29/116, showed significantly positive values at two of the stations and insignificantly positive values at the other two.

On the other hand, Co. 290, while showing a significantly negative regression value at each of three stations (Table 6) and also in the aggregate of all tests (Table 4), showed a positive value approaching significance at Rosewood. Trends observed with C.P. 28/11 and 28/19 from station to station showed significant reversals.

TABLE 5.—*Values for variety × year interaction at each of four stations as based on data given in Table 1.*

Year	Co. 281	Co. 290	C. P. 28/11	C. P. 28/19	C. P. 29/116	C. P. 29/320
			Raceland			
1937	0.7	9.7	13.9	1.9	−25.2	− 1.2
1938	− 1.6	2.6	− 4.0	2.6	− 1.7	1.9
1939	− 4.8	− 6.6	− 4.2	− 4.2	18.5	1.1
1940	5.5	− 5.9	− 5.9	− 0.5	8.4	− 1.8
			Albania			
1937	1.6	3.1	− 9.8	14.2	−27.5	18.3
1938	−30.5	14.8	19.9	4.3	11.8	−20.4
1939	14.2	4.9	−15.8	− 9.8	− 0.5	6.9
1940	14.6	−22.9	5.6	− 8.8	16.1	− 4.7
			Rosewood			
1937	− 2.0	− 3.8	− 9.9	5.8	12.1	− 2.3
1938	− 8.8	− 2.8	− 3.5	8.0	− 8.3	15.5
1939	9.6	− 0.6	1.7	3.6	−19.7	5.7
1940	1.2	7.2	11.9	−17.4	16.1	−18.9
			Alma			
1937	2.5	8.7	− 4.1	−14.4	−14.7	22.0
1938	−12.0	16.4	− 7.2	2.3	− 0.4	0.9
1939	− 7.0	8.2	−19.0	−11.3	26.2	2.9
1940	16.5	−33.7	30.3	23.6	−10.9	−25.8

TABLE 6.—*Linear regression of varietal interaction value (Table 5) on year for each of four stations in Louisiana during the period 1937–40, inclusive.*

Variety	Linear regression			
	Raceland	Albania	Rosewood	Alma
C. P. 29/116......	121.0**	118.5**	0.6	38.0
Co. 281..........	12.6	83.7**	28.0	47.0*
C. P. 28/11.......	−59.2**	10.5	70.6**	91.4**
C. P. 28/19.......	−14.0	−83.1**	−74.0**	100.4**
Co. 290..........	−56.0**	−87.9**	35.2	−135.4**
C. P. 29/320......	− 2.6	−41.7	−59.6**	−141.4**

Test of significance

P.	Linear regression value
0.05*	±42.63
0.01†	±56.12

DISCUSSION

It is quite apparent that, under prevailing conditions, the relative performance of individual varieties was strongly differential as related to differences between stations and also as related to differences between years. Therefore, as pointed out above, the experimental error

derived from results of a single test does not afford a satisfactory basis for selecting the varieties which are likely to prove most satisfactory under any other conditions. Conversely, in eliminating varieties on the basis of such a test a greater degree of tolerance should be allowed than would be indicated by odds based on experimental error. In this connection odds based on the appropriate interaction variance maintained in past experiments would probably afford a fairly safe criterion.

The most interesting disclosure brought out by this analysis is the evidence that there has been a progressive change in the relative performance of the different varieties from year to year. To explain this it is necessary to assume that certain factors have tended (a) to make some of the varieties more and more productive from year to year, or (b) to make some of them less and less productive from year to year, or (c) to result in a combination of a and b. In this case at least our most logical assumption would seem to be that there has been a gradual decrease in the yield capacity of certain of the varieties associated with increasingly severe injury from prevalent diseases to which the varieties are susceptible. Such a condition would no doubt be brought about by a gradual increase in the extent of mosaic infection which, according to Summers (9), commonly occurs in susceptible varieties during the course of time.

Abbott (1) has shown that red rot (*Colletotrichum falcatum*) as found under Louisiana conditions comprises a variety of physiologic strains differing greatly among themselves as to degree of injury caused to individual varieties of sugarcane. His results show further that during the period 1933–37, when the variety C.P. 807 was being rapidly extended in commercial plantings in Louisiana, there occurred a gradual increase in the prevalence of a strain of red rot fungus found to be especially virulent on C.P. 807. Results of varietal yield tests during the same period reported by Arceneaux, Gibbens, and Krumbhaar (2) indicated a significant decline in relative yields of C.P. 807 as compared with yields from Co. 290.

Rands and Dopp (10) have reported rather striking physiological differences between different isolates of *Pythium arrhenomanes* from Louisiana. These investigators and also Abbott (1) have suggested that certain strains of specifically injurious organisms may be stimulated to multiply in increasing proportion in response to continued cultivation of varieties that they are able to attack.

Thus, in interpreting observed changes in varietal yield trends with respect to time, it would seem logical to assume that a negative regression value indicates a decrease in yield capacity. It may be assumed further, that none of the varieties showing positive regression values has increased in absolute yield capacity during the period; therefore, the variety showing the highest positive regression value has, in all probability, changed the least. As a matter of fact the yield capacity of that particular variety may have actually decreased, but it would of course be difficult to detect such a change.

An examination of the data given in Table 4 will show that while linear regression values calculated for Co. 281 amd C.P. 28/11 are positive with respect to the group as a whole, they are in both cases

considerably below that calculated for C.P. 29/116. From varietal regression values given in Table 5 it is possible to measure the relationship maintained by each variety with respect to C.P. 29/116, our hypothetically most uniformly performing variety. The standard deviation of such a difference may be estimated as $\sigma\sqrt{k}\sqrt{40}$ or ± 67.12. ($\sigma = 2.1663$; $k = 24$.) Varietal linear regression data given in Table 4 may therefore be summarized as follows:

Variety	Linear regression of varietal interaction value on year	
	Observed value	Differences as compared with C. P. 29/116
C. P. 29/116	278.1**	—
Co. 281	169.9**	−108.2
C. P. 28/11	112.9	−165.2*
C. P. 28/19	− 70.7	−348.8**
Co. 290	−244.1**	−522.2**
C. P. 29/320	−245.3**	−523.4**
Value for:		
P. = .05*	± 85.27	±132.09
P. = .01**	±112.27	±173.91

It is thus seen that, in comparison with C.P. 29/116, four of the other five varieties have shown significant linear declines in yield over the 4-year period. The drop shown by Co. 281 is somewhat below the level of statistical significance.

Assuming, as suggested above, that a negative regression in varietal yield as compared with C.P. 29/116 probably represents a decrease in varietal yield capacity resulting from the encroachment of a disease or diseases on the clone, it does not necessarily follow, and in fact it would seem definitely improbable, that such a change would manifest itself in the same degree at all localities. The spread of a disease such as mosaic may take place much more rapidly under certain conditions than under others. A rare and specifically virulent strain of a given disease organism may not be present in the same proportion at all stations and may be entirely absent at some places. Therefore differences with respect to change in yield status displayed by some of the varieties at different stations as observed in results summarized in Table 6 may readily be expected. A study of disease conditions as occurring in the various localities might throw interesting light on the factors involved in specific cases.

The gradual change in yield relationship observed among the different varieties of the group is of unquestionable importance in the interpretation of varietal yield data covered by this particular study. In a broader sense these observations throw interesting light on a phenomenon frequently discussed in sugarcane literature and which, for the lack of a better term, has been commonly designated as "varietal failure". In many cases the so-called "failure" of a variety

has quite obviously been caused by the spread of a disease previously not present in the particular region. For instance the introduction and spread of mosaic in Louisiana no doubt largely contributed to the "failure" of Louisiana Purple and D 74. On the other hand, as pointed out above, the effect of diseases already present in a given region may become increasingly severe from year to year due to (a) an increase in the prevalence of a disease within the clone or (b) an increase in the prevalence of specifically injurious forms of a disease organism. It is probable that the same applies in a greater or lesser degree to any plant propagated by vegetative means. Thus, while vegetative propagation insures, on the whole, the preservation of the particular plant in a genetically stable condition, we cannot overlook the fact that the performance of such a plant may be greatly conditioned by obscure as well as radical changes in the environment with respect to diseases and possibly other factors. An analysis of trends in the relative yield of varieties from year to year in the manner illustrated above offers a convenient critical test of possible changes in yield capacity as related to time.

SUMMARY

A study of cane yield data obtained in variety tests at four stations in Louisiana during the period 1937–40 has revealed significant increases in variance due to the interaction of (a) variety × station, (b) variety × year, and (c) variety × station × year. An analysis of the differential response of varieties to differences between years showed that, over the period covered, certain of the varieties tended to give relatively increased yields from year to year while others displayed a significantly opposite trend. Evidence is cited to show that important changes in the environment with respect to diseases may occur from year to year and it is pointed out that the performance of a given plant may be greatly conditioned by such changes. The importance of possible changes in varietal yield capacity over a period of time is emphasized and a method whereby such changes may be measured is illustrated.

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INDUCED VIVIPARY IN THREE VARIETIES OF BARLEY POSSESSING EXTREME DORMANCY[1]

MERRITT N. POPE AND EDGAR BROWN[2]

IN 1941, the junior author made an extensive test of dormancy in over 4,000 varieties of barley grown in the agronomic nursery at Sacaton, Ariz. Among these were three winter-type sorts that proved to be very dormant. Since vivipary had been successfully induced in two common spring types,[3] it seemed desirable to determine whether varieties with dormant tendencies also could be made to produce seedlings while growing on the parent plant. The regular germinating behavior of the three winter varieties, together with that of a spring variety used as a check, is shown in Table 1.

TABLE 1.—*Germination at two temperatures of a normal spring barley and three winter varieties showing dormancy at three periods after harvest.*

C. I. No.	1941 Sacatom row No.	Variety	Type	Seeds sprouting at indicated period after harvest (5 seeds used in each test)					
				2 weeks		6 weeks		14 weeks	
				86°F	68°F	86°F	68°F	86°F	68°F
2330*	723	Manchuria	Spring	1	4	3	4	—	—
1260	394	Dentil	Winter	0	0	0	1	0	4
1222	369	Abyssinian	Winter	0	0	0	2	0	5
1456†	499	Meliton	Winter	0	0	0	0	1	4

*Another seed lot of this variety similarly showed no indication of dormancy either immediately after harvest or when stored at room temperature for 9 months.

†A sample, when tested with the lemma and coat removed, gave complete germination at both 86° and 68° F in 6 days. A check test at the same time (7 weeks after harvest) gave complete germination at 68° F but not at 86° F. This variety gave complete germination in 6 days when tested at 50° F at 14 weeks after harvest.

On January 8, 1942, seeds of the three winter varieties from the same nursery rows as those tested (Table 1), together with seeds of Manchuria (C. I. 2330)[4] grown at the Arlington greenhouse, Arlington, Va., in 1940, were planted in the greenhouse at the Bureau of Plant Industry Station, Beltsville, Md. In April, two spikes of each of the winter varieties were tagged when a part of the spikelets were in flower. At about the same time the Manchuria flowers on five spikes were hand-pollinated. After the seeds had developed 7 to 10 days, the lateral flowers were stripped off and filter paper was inserted over the exposed embryo ends of the seeds and kept wet. The Manchuria seeds were definitely germinating on the 15th day after pollination, but the progress in the winter varieties was not observed. The data obtained are presented in Table 2.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture. Received for publication October 22, 1942.

[2]Agronomist and Collaborator, formerly Principal Botanist, respectively.

[3]POPE, MERRITT N. Jour. Amer. Soc. Agron., 33:850–851. 1941.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

At harvest, 24 to 27 days after flowering, 21 to 58% of the treated seeds, depending upon the variety, had produced seedlings, and every treated spike showed at least one seedling. Spikes of each variety that had the longest plumules are shown in Fig. 1.

As might be expected, there was considerable variation in the stage

FIG. 1.—Viviparous seedlings in the spikes of one spring variety and three winter varieties of barley. A, Manchuria (C. I. 2330) 6-rowed, white, spring; B, Dentil (C. I. 1260) 2-rowed, white, winter; C, Abyssinian (C. I. 1222) 6-rowed, black, winter; D, Meliton (C. I. 1456) 2-rowed, black, winter.

TABLE 2.—*Induced vivipary in spring and winter barleys.*

C. I. No.	Variety	Type	No. of spikes	Approximate date flowered, April	Age at treatment, days	Age at harvest, days	No. of seeds treated	No. of seedlings produced	Maximum length of plumules, mm
2330	Manchuria	Spring	5	13*	7	25	46	19	55
1260	Dentil	Winter	2	12	10	24	31	18	65
1222	Abyssinian	Winter	2	15	9	24	38	8	64
1456	Meliton	Winter	2	7	10	27	35	11	67

*Hand-pollinated on this date.

of development of the seedlings, but the maximum plumule length was approximately the same in the spring and winter types. This suggests that at this early stage of growth in the varieties tested (1) no more dormancy exists *in the embryo* of the winter than in the spring barley, and (2) that the seed coats of the spring and winter barleys were equally permeable.

NOTES

WEAK NECK IN SORGHUM[1]

WEAK neck in sorghum was first described in 1938 by Swanson[2] as a disease of dwarf varieties of grain sorghums adapted to combine harvesting. The chief symptoms mentioned were the occurrence of poorly developed heads containing light-weight seed, the breaking over of the heads, and the disintegration of the tissues of the peduncle, especially at its base or the top node where the break-over most frequently occurs. Swanson suggested that the trouble might be due to either a pathogenic organism or a physiologic breakdown of the tissues of the peduncle. During the past 5 years studies and observations have been made in the laboratory, greenhouse, and field to determine whether weak neck is due to a definite causal organism, unfavorable environment, or an inherent weakness of certain varieties. It seems advisable to present a brief summary of the results obtained.

During the course of investigations, a large number of affected plants were examined and found to have healthy crowns and roots. The culms below the nodes of the diseased peduncles produced vigorous axillary branches. Soil disinfection failed to inhibit or reduce the development of weak neck in susceptible varieties. When cultures of the organisms most frequently isolated from affected plants were added to steamed soil, weak neck was no more severe in the

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture, cooperating with the Department of Botany (contribution No. 441), Kansas Agricultural Experiment Station, Manhattan, Kans.

[2]SWANSON, A. F. "Weak neck" in sorghum. Jour. Amer. Soc. Agron., 30:720–724. 1938.

plants grown in this soil than it was in plants grown in steamed uninoculated soil. These results indicate that the malady is not soil-borne, and apparently not systemic.

The possibility of weak neck being caused by local infection of the peduncle or rachis was eliminated by examination of hundreds of affected plants in the field, greenhouse, and laboratory. The interior of the rachises and peduncles of scores of affected culms yielded no organisms when sections were plated aseptically on nutrient agar. Other peduncles and rachises that showed evidence of having been invaded by some microorganism yielded *Fusarium moniliforme* most frequently. Other species of *Fusarium*, bacteria, and species of *Helminthosporium* and *Alternaria* were also isolated. Similar isolations, however, were made repeatedly from lesions on susceptible plants showing no symptoms of weak neck and also from lesions on varieties not generally affected by weak neck. Spraying the heads and peduncles of sorghum plants with suspensions of these isolates had no more effect than spraying with sterile water. When these suspensions were injected into the peduncle hypodermically, however, or when the tissues were merely wounded, infection of the injured area followed. It was found that plants that developed extensive lesions after being thus inoculated or injured, especially in the peduncle, frequently showed symptoms of weak neck somewhat earlier than did most uninjured plants. The same was true of peduncles frequently found invaded by the corn ear worm.

The infestation of weak neck plants with aphids suggested them as a possible casual factor. However, when aphids and red spiders were eliminated by means of sprays or of soil treatment with selenium, the severity of weak neck was not reduced except that aphid-infested culms were less vigorous and succumbed to weak neck sooner than did those not infested with these pests. Thus, both bacterial and fungous invasion and insect infestation, while not primarily causing weak neck, seemed to aggravate it. This readily explains why weak neck was regarded as an infectious disease.[3]

Environmental factors, such as temperature, moisture, soil type, and fertility, were not found to be wholly responsible for the condition called weak neck in sorghum; however, Colby milo subjected to drought before, during, or after heading developed weak neck earlier than did plants continuously supplied with ample moisture. In six periodic plantings of Colby milo made outdoors at Arlington, Va., from May 15 to July 1, the first two plantings showed symptoms of weak neck by October 9 and the next three were similarly affected a month later. The latest planting failed to mature. Successive plantings of Colby milo made in the greenhouse from March 10 to May 10 all developed weak neck ultimately, while comparable plantings of resistant Weskan did not. Weak neck developed in plants grown in various types of soil, including rich compost soil, Keyport silt loam, and poor sandy soil, showing that a definite soil type is not requisite. Extreme heat, drought, or growth in soil with a low water-holding capacity undoubtedly may hasten the appearance of weak neck or

[3]See footnote 2.

possibly make it more pronounced, but none of these is the sole cause of it, because weak neck has occurred in the absence of all of these conditions. Extreme drought or heat when the seed is in the milk or soft dough stage may curtail kernel filling and cause premature ripening and undersized kernels. Such prematurely ripened heads and culms are the first to go down with weak neck and, as a consequence, shriveled kernels often have been associated with weak neck. This association, however, does not always obtain.

It is concluded that weak neck is not a disease caused by a pathogen but is a condition of over-ripeness accompanied by weakness of tissues in the rachises and peduncles, especially of the primary culms, in certain varieties of sorghum. This condition may be aggravated by the subsequent invasion of organisms that produce decay of the peduncle. In some varieties, especially the sorgos and many kafirs, the seeds ripen to a low moisture content while the rachis and peduncle are yet relatively green and turgid. In other varieties, particularly the milos and feteritas and many of their derivatives, the rachis loses moisture rapidly and becomes straw-colored to ashy white very soon after the seeds reach the hard dough stage. The interior tissues of the rachis become dry rapidly and this drying continues down the peduncle, which becomes spongy and weak. If wet weather follows, the spongy peduncle becomes water-soaked and limp and is easily broken over by the wind and the weight of the head. In the sheath surrounding the base of the peduncle there generally is a slimy liquid containing honey dew, bacteria, and other microorganisms. This liquid not only softens the peduncle so that it breaks over at this point, but it also contains organisms that subsequently invade and decay the peduncle, thus bringing about the final stage of weak neck.

Weak neck has become a farm problem rather recently or since the advent of the combine harvesting of grain sorghum. Before that time all sorghum varieties were harvested shortly after the grain was ripe, regardless of the stage of maturity of the rest of the plant. Sorghum that is to be combined, however, usually is not harvested until after freezing weather or until the rachises and peduncles are no longer sappy, so that the threshed grain will be sufficiently dry for safe storage. The dwarf varieties that were developed for combining are largely derived from milo, which is early maturing and has a dry stem with a relatively thin rind, both of which are conducive to the development of weak neck. Since the trouble known as weak neck seems to be largely a varietal characteristic, the remedy apparently lies in developing combine types of sorghum that ripen more like sorgo and kafir and less like milo. A measure of success in this direction has been attained in the development of such varieties as Westlane and Kalo selection H C 617. Another possibility is the development of combine varieties having more strengthening tissue that will support the head after the peduncle is dry. Some progress has been made also toward this objective.—R. W. LEUKEL, L. E. MELCHERS, and A. F. SWANSON, *Division of Cereal Crops and Diseases, Bureau of Industry, U. S. Dept. of Agriculture, and the Department of Botany, Kansas Agricultural Experiment Station.*

MANGANESE AND ASCORBIC ACID FORMATION

THE concept that the rate of ascorbic acid synthesis is accelerated by an increased manganese supply was first developed in biochemical studies of liver tissue,[1] although recent experiments[2] have failed to confirm this conclusion. Subsequently, there have been reports[3] that the ascorbic acid content of tomato fruits is increased when manganese is added to soils deficient in this element.

An experiment has been recently completed at this laboratory which was designed primarily to test the effects of deficiencies of micro-nutrient elements on the vitamin content of tomatoes. Tomato plants were grown to maturity in the greenhouse in a crushed pyrex glass substrate supplied at regular intervals with rigidly purified nutrient solution. The apparatus was specifically designed to minimize contamination of the nutrient solution. The experimental design was that of a Latin square and in addition to the control plants supplied with complete nutrient, one of the seven treatments consisted of manganese-deficient nutrient cultures. The experimental details will be reported elsewhere.

At the conclusion of the experiment, the plants grown in the manganese deficient cultures were 58% as tall, had 66% as many internodes, and the dry weight of aerial vegetative parts was approximately 30% as great as comparable control plants. The total fresh weight of fruit produced in the manganese-deficient treatment was 25% of the control and the number of fruits produced on each plant was materially less. All differences are highly significant when analyzed statistically.

The leaflets of the upper third of deficient plants were dead in all replicates and the growing point was no longer functional at the conclusion of the experiment. Lower leaves were extremely chlorotic. Furthermore, a fruit symptom developed in manganese-deficient cultures which has not previously been described to our knowledge. The fruit produced by these plants remained green in localized areas at the stem end. When the remaining portions of the fruit became a deep red at maturity, these areas turned a yellowish green color with pin points of brown distributed through them at random. The areas never became red. In addition to external symptoms, chemical analyses were made on the second, fourth, and sixth fruits which ripened on each plant. The leaflets from the top, middle, and lower third of each plant were also analyzed. These data are reported in Table 1.

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[1]RUDRA, M. N. Role of manganese in the biochemical synthesis of ascorbic acid: The precursors of ascorbic acid in rat tissue. Osterr. Chem.-Ztg., 42:315–317. 1939.

——————. Role of manganese in the biological synthesis of ascorbic acid. Nature, 144: 868. 1939.

[2]BOYER, P. D., SHAW, J. H., and PHILLIPS, P. H. Studies on manganese deficiency in the rat. Jour. Biol. Chem., 143:417–425. 1942.

[3]HESTER, J. B. Manganese and vitamin C. Science, 93:401. 1941.

——————, and HALL, H. F. Quality of tomatoes through sound farming practices. Agr. Res. Bul. No. 4, Campbell Soup Co. 1942.

——————. Influence of soil fertility upon the quality of tomatoes. Soil Sci. Soc. of Amer. Proc., 6:243–245. 1941.

TABLE I.—*Manganese analyses in parts per million of plants grown in complete and manganese-deficient culture solutions.*

Part of plant	Complete culture solution		Mn-deficient culture solution	
	Mean±S.E.	Number of analyses	Mean±S.E.	Number of analyses
Fruit*...............	1.7±0.17	11	0.2±0.02	9
Leaflets:†				
A, top ⅓ of plant....	69.7± 9.08	7	5.6±1.33‡	5
B, middle ⅓ of plant.	248.3±29.95	7	5.3±0.94	6
C, bottom ⅓ of plant	398.0±23.79	7	5.4±0.67	7

*Figures are computed per unit fresh weight of fruit.
†Figures are computed per unit dry weight of leaflets.
‡Many of these leaflets were dead at time of harvest.

It is obvious that manganese-deficient plants had very small amounts of manganese in both fruit and vegetative parts as compared to the controls. The manganese content of the control fruits compares favorably with that reported in the literature[4] for tomatoes grown under normal cultural practices on the farm.

The first, third, and fifth fruits to ripen on each plant were analyzed for ascorbic acid. The average of 19 analyses of manganese-deficient fruits was 20.2 ± 0.49 mgms of ascorbic acid per 100 grams of fresh weight, and the average of 27 analyses of the control fruits was 20.0 ± 0.46 mgms. Within the limits of error there is no statistically significant difference in these means. Previous data[5] show that the small differences in climatic environmental factors in the field may have pronounced effects upon ascorbic acid content. In this particular experiment in a comparatively uniform greenhouse environment, a comparison of the replications indicates that any variations in the environmental conditions which might have existed did not produce a statistically significant effect on the ascorbic acid content of the fruit.

The lack of manganese in this experiment resulted in severe deficiency symptoms accompanied by significantly less growth and fruitfulness but did not significantly affect the ascorbic acid content. The reports of increased ascorbic acid in tomato fruits resulting from the addition of soluble manganese to deficient soils have led to the assumption that the element manganese is directly concerned. The data reported in this paper do not support this hypothesis.—C. B. LYON and K. C. BEESON, *U. S. Plant Soil and Nutrition Laboratory, Ithaca, N. Y.*

[4]BEESON, K. C. The mineral composition of crops with particular reference to the soils in which they were grown. U. S. D. A. Misc. Pub. 369. 1941.

[5]HAMNER, K. C., LYON, C. B., and HAMNER, C. L. Effect of mineral nutrition on the ascorbic acid content of the tomato. Bot. Gaz., 103:586–615. 1942.

BOOK REVIEW

THE PRINCIPLES OF FIELD DRAINAGE

By H. H. Nicholson. Cambridge: At the University Press; New York: The Macmillan Co. XI + 165 pages, illus. 1942. $3.

THE author of this small volume is lecturer in Agricultural Chemistry in the School of Agriculture, University of Cambridge. It was apparently written to fill a need for more information on the subject incident to the inception of the British government's schemes of assistance for the various forms of land drainage.

According to the author, the means for acquiring such knowledge have been extremely meager. It aims to assist those whose business is to organize, devise, advise on, and supervise works of field drainage, and brings to bear on the subject principles of soil science, 10 years' study by the author of drainage problems, and the results of cooperation with many war agricultural executive officials and farmers dealing with such problems.

The book covers such matters as past and present interest in drainage in Great Britain, soil moisture, percolation, premeability and water tables, and field drainage problems and their solution. Special chapters are also devoted to ditches, tile drainage, mole draining, draining of special areas, river flow, and floods. An appendix gives some special information on government aid, tables useful in drainage work, and a bibliography of the subject.

As the author points out there is not too much published information on this important subject, so such a book should be very welcome not only to the British worker but also to anyone interested in drainage problems in the United States. (R. C. C.)

AGRONOMIC AFFAIRS

THE ST. LOUIS CONFERENCE ON POST-WAR NITROGEN PROBLEMS

AS ANNOUNCED in the November 1942 number of the JOURNAL, a conference was held on November 10th in St. Louis to discuss the general topic of "The Service of Abundant Low-cost Nitrogen to American Agriculture and American Life." Doctor Robert M. Salter presided and Mr. H. R. Smalley served as Secretary. Abstracts of the papers presented at the conference have been assembled by Mr. Smalley for publication in the JOURNAL. He is also preparing a mimeographed Proceedings which will include both the preliminary conference held in Washington, D. C., September 23rd and the St. Louis conference held November 10th, together with the personnel of the Joint Committee and of the Subcommittees. Copies of the Proceeding may be obtained upon request to Mr. Smalley, the National Fertilizer Association, 616 Investment Building, Washington, D. C.

The abstracts of the papers presented in St. Louis follow.

THE UTILIZATION OF NITROGEN WITH NONLEGUME COVER CROPS FOR GREEN MANURING AND EROSION CONTROL

A. In the South, by R. W. Cummings of North Carolina.—The relative merits of legume and nonlegume cover crops were discussed, and the following lines of research were suggested:

1. For winter cover crops in rotation with summer crops such as cotton, corn, and peanuts where little residual nitrogen from the preceding crop fertilization is present. Such experiments should include (a) nitrogen applications in fall and late winter to stimulate vegetative growth; (b) nitrogen applications at time of turning the cover crop under; and (c) nitrogen application only to the succeeding crop with and without winter cover.

The rates of application should go high enough largely to eliminate nitrogen as a limiting factor in the growth either of the cover crop or the succeeding crop and at least high enough to supply as much nitrogen as is obtained from winter legumes. Winter legume and no cover crop checks should be included in such comparisons and supplemental nitrogen treatments should be used with the legumes and bare plots. The actual and relative value of legumes with and without supplemental nitrogen and nonlegumes with and without supplemental nitrogen should be determined without bias. Such experiments should be continued on the same land for more than one year in order to evaluate properly the effects of the different systems on building and maintaining the productive level of the soil. Phosphates, potash, and lime should of course be eliminated as limiting factors.

2. For summer cover crops in rotation with such crops as potatoes which are grown at a relatively high fertility level and where there is likely to be residual nitrogen in the soil from potato fertilization. The cover crops might be sudan grass, sorghum, millet, or soybeans, and although the effect on the soil may be slightly physical, the nitrogen levels should at least be high enough to eliminate nitrogen as a limiting factor in potato production.

In order to establish fundamental principles it is desirable to extend the inves-

tigations into ranges of nitrogen supplement which at present would not be profitable.

B. In the North, by Firman E. Bear of New Jersey.—In order to avoid nitrogen starvation from the use of nonlegume cover crops it is necessary to resort to one of four procedures, *viz.*, (a) plow the material under while it is young and before its carbon content has reached its highest level; (b) add a nitrogen fertilizer to the material before plowing it under; (c) plow the material under long enough in advance of planting a crop to permit of enough decomposition to lower its carbon-nitrogen ratio to 30:1 or less; (d) add extra nitrogen to the fertilizer that is used at planting time.

The reasons for growing nonlegume cover crops instead of legumes under some conditions are (a) that the seed of the nonlegume cover crop is much less expensive than that of the legume; (b) the lime and fertilizer requirements for adequate growth of the nonlegumes are much lower; (c) the rate of growth of the nonlegumes is often much more rapid; and (d) the nonlegumes are much less subject to winterkilling.

The merit of rye and ryegrass as cover crops was emphasized.

C. For Erosion Control, by T. S. Buie of the Soil Conservation Service.—With the prospect of cheap commercial nitrogen in the post-war period, nonlegumes will compete more actively with legumes than heretofore, and there are almost unlimited possibilities for the use of such crops as oats, rye, and barley for winter cover. Rye grass also has considerable promise under certain conditions. Some of the reasons why small grains are particularly suitable for winter cover in the Southeast are (a) the seed may be produced on the farm; (b) farmers understand small grains; (c) it would not be necessary to purchase expensive machinery; (d) inoculation is not necessary; (e) the small grains are not unduly influenced by the shortage of moisture at planting time; (f) they may be planted early in the season, thus affording quick cover; (g) they usually make sufficient growth to provide protection to the ground before heavy winter rains occur; (h) they provide grazing under proper conditions; and (i) they provide an abundance of organic matter.

Some points on which further research is needed include (a) the effect of nitrogen on the early growth of the plant; (b) the effect of nitrogen on the total production of green material; (c) the effect of nitrogen on the protein content of the plant with possibility of substantial increase; (d) the form, rate, and placement of nitrogen fertilizer to accomplish desirable effects; and (e) the use of nitrogen in various forms and time of application as means of aiding the decomposition of plant residues, both nonleguminous and leguminous.

THE UTILIZATION OF NITROGEN WITH CROP RESIDUES AND MULCHES

A. In the Midwest, by A. G. Norman of Iowa.—The answer to the problem as to whether nitrogen can be utilized effectively with crop residues resolves itself into a study of the decomposition of mature materials which are mostly of low-nitrogen content. The actual nitrogen requirement of such materials for decomposition at the maximum rate is not yet known with assurance. It has been stated that unless the nitrogen content is 1.8% or over, early liberation of ammonia will not occur. This does not mean, however, that materials of lower nitrogen content, if supplied with additional inorganic nitrogen, will cause nitrogen immobilization to occur microbially till the total nitrogen content is of this order.

Most experiments examining this point have been conducted *out of soil* under conditions that may not permit of the development of a population entirely similar to that which might become dominant *in soil*. In general, immobilization has occurred so that the total nitrogen content reached only about 1.2 or 1.3%. Recent studies in soil, however, suggest that less may ordinarily be required and that the effect of a small deficiency of nitrogen is not great in its influence on rate of decomposition. It may be in fact that when additional inorganic nitrogen is present, the microbial population indulges in "luxury consumption" of nitrogen by preferentially utilizing the available inorganic form in place of the organic nitrogen of the mature residues.

Comparative studies with mature crop residues used as surface mulches in humid areas have not yet been made. Surface mulches will not be entirely comparable to out-of-soil laboratory experiments because of the leaching effects of rainfall and the possibility of loss of any free ammonia.

B. In the Wheat Belt, by F. L. Duley of the Soil Conservation Service.—The soils of the Wheat Belt were originally fairly well supplied with total nitrogen. Crop rotation, including legumes, for the purpose of maintaining total or available fertility is not applicable on much of the wheat-growing area of the western United States. In experiments conducted in the Great Plains and in the Pacific Northwest, it was found that crop yields can be increased by using commercial nitrogen, but the increases in many cases have not been profitable. Leaving the straw from combined wheat and other residues on the surface has been effective in protecting land against erosion by wind and water, but this practice has raised questions concerning nitrate supply, and the advisability of applying some nitrogen in order to narrow the carbon-nitrogen ratio. Some promising results have been obtained from subsurface tillage, and it may be possible by proper manipulation to synchronize the period of greatest nitrate production with the time of maximum requirement for available nitrogen by the crop.

It would appear that the use of nitrogenous fertilizer where crop residues are left on the surface might result in yield increases for two reasons, *viz.*, (a) through the use of residues it is possible to increase to some extent the available soil moisture; thus making it possible to utilize a larger amount of soluble plant-food material; (b) the amount of nitrate present in many soils and during certain years may be less than the amount needed for maximum production.

NITROGEN IN THE PRODUCTION OF CORN AND SMALL GRAINS

A. In the South, by Randall J. Jones of Alabama.—The deficiency of nitrogen in southern soils is one outstanding factor causing low yields of corn and small grains in the South. An analysis of data obtained in experiments conducted in South Carolina, Alabama, and Mississippi shows that application of nitrogen greatly increased the yield of corn. On the average the increases from different rates of application of nitrate of soda were as follows: No nitrate (phosphate and potash only), 21 bushels; 100 pounds, 28 bushels; 200 pounds, 34 bushels; and 300 pounds, 37 bushels.

In Alabama results obtained over a period of 12 years at seven locations show that for each 12-pound increment of nitrogen, ranging from 0 to 36 pounds, there is a corresponding increase in the corn yield amounting to 8 bushels for the first increment, 8 bushels for the second, and 6 bushels for the third. It is thought that corn yields can be further increased by adding still more nitrogen, and new experiments should be conducted to determine the maximum yield in corn that can be obtained.

Experiments on oats show that without nitrogen the yield was 16 bushels; with 100 pounds of nitrate of soda, 29 bushels; with 200 pounds, 39 bushels; and with 300 pounds, 46 bushels. When higher rates of nitrogen are used for corn and small grains it is likely that additional applications of phosphate and potash will be required.

The production of adequate amounts of grain remains one of the most serious problems in southern agriculture. Cheap nitrogen would help greatly in the solution of this problem.

B. In the North, by George D. Scarseth of Indiana.—Results obtained in recent experiments in Indiana and Ohio indicate that 2 pounds of commercial nitrogen will make 1 bushel of corn where other factors are not limiting. Where corn yields are not more than 30 or 40 bushels per acre because of general low fertility, big increases in yields can be obtained from the direct use of nitrogen when phosphate and potash are also supplied in adequate amounts. Low-priced nitrogen may make it possible to utilize such highly carbonaceous crop residues as corn stalks to better advantage for soil building by narrowing the carbon-nitrogen ratio through the direct application of nitrogen. The use of 2,000 additional tons of nitrogen for hybrid seed corn production in the commercial Corn Belt is highly desirable. The greatest benefit from low-priced nitrogen will be derived by grain farmers who are now feeling the effect of impoverished soils as a result of a drastic soil-depleting system. Low-priced nitrogen will offer these farmers a chance to restore the soil fertility and remain in the cash grain business.

NITROGEN IN THE PRODUCTION OF PASTURES AND HAY

Allied Chemical and Dye Corp., by S. B. Haskell, Barrett Division

For as long a time as clovers and other legumes come and go in permanent pastures and in meadows, as the alfalfa in old seedings gives way to grass, as legumes "burn out" from new seedings or yield to other adverse influences, commercial nitrogen as used on pastures and meadows will perform a great service The lower the price at which this nitrogen can be offered, the greater the promise of such service. The question is, therefore, what new research relative to use of nitrogen on pastures and other grasslands, or redirection of old research, may be needed.

Without denying the value of study of many refinements in practice, the three major changes in redirection of research which seem most important are (a) a definition of the service expected of the nitrogen used on pastures and grasslands, whether it is to be considered supplementary to the legume nitrogen grown and fed on the farm or competitive; (b) if conditions indicate the need of additional nitrogen, the first increment should be in the order of 40 pounds of nitrogen per acre; and (c) the greatest opportunity for service of low-priced nitrogen on grasslands lies in a grassland agriculture.

Proposed research should therefore be considered a part of the much larger problem and this is the soil-conserving grassland agriculture as compared with the soil-destructive tillage agriculture. When this major problem is attacked, it may be recognized that returns per day of human time may be a better criterion than returns per acre for in much of the northeastern dairy area the bottleneck is that of labor rather than that of land.

PROBLEMS OF BALANCE, CROP COMPOSITION AND QUALITY WITH HEAVY NITROGEN FERTILIZATION

A. Vegetable Crops, by H. H. Zimmerley of Virginia.—Results of a survey among horticulturists of 14 states were presented. Most investigators favor a flexible national program of research to determine the maximum utilization of nitrogen for vegetables during the post-war period. Many vegetable growers are already using maximum quantities on certain soils, and additional research is needed to determine maximum limits under a great variety of conditions. In one midwestern state where growers normally use 4 to 8 pounds of nitrogen per acre on tomatoes, experiments have shown that on some soils tomatoes have responded to as much as 120 pounds of nitrogen per acre plowed under, but further research is needed with this method of application. Such experiments should include heavy applications of nitrogen in connection with crop residues, or to non-leguminous soil-improving crops that precede vegetables, and side-dressing during the growing period. There is considerable data available that relates to the optimum NPK balance for many vegetable crops, but where such data are lacking additional experiments should be conducted if possible. The use of plant tissue tests at different stages of growth will assist in detecting even temporary conditions of nutritional unbalance. Data soon to be published relative to the fertilization of turnip greens will show very clearly that both the fertilizer applied to the crop and the nutrient level of the soil significantly affect the mineral composition of the plant.

B. Deciduous Fruits, by J. H. Gourley of Ohio.—A survey was made among horticulturists to obtain opinions as to the possible use of more nitrogen on tree fruits, ornamental plantings, and forests. Replies indicate clearly that the use of nitrogen and other fertilizers on deciduous fruit trees, evergreens, and other ornamental plantings is in its infancy, that fertilization may bring a new era in American horticulture and forestry. Fruit trees in commercial plantings are usually rather well supplied with nitrogen at present. There is some tendency to use a little too much nitrogen, which results in poor quality. It is suggested that fertilizer should be applied over the entire orchard instead of beneath the trees only. This would benefit the trees and also produce more mulching material. More frequent applications of fertilizers to fruit trees and berry crops is suggested; also heavy applications of nitrogen on fruit trees on light soils in the South to overcome infestation with nematodes and winter injury. There is considerable interest in a more general fertilization of nut and tung trees.

BREEDING CROPS FOR PRODUCTION AT HIGH FERTILITY LEVELS

By O. S. Aamodt, *Division of Forage Crops and Diseases, U. S. Dept. of Agriculture*

In a well-balanced cropping system the two forms of nitrogen (legume and chemical) should be complements to each other rather than competitors. Legumes, and the grasses usually associated with them, have a much greater function in soil improvement and crop production than the mere fixing of nitrogen from the atmosphere. Many other factors in addition to this important element are involved in the production of maximum or economical yields with the aid of legumes. We need to consider the requirements of the cropping system as a whole rather than the special nitrogen requirements of a particular crop, usually a soil-depleting, cultivated annual crop, in that system. We want to maximize production, and this can be done only if we strive for a favorable balance of all the important

nutrients, organic matter, microflora, and suitable physical condition of the soil. The plant environment needs to be geared to a level commensurate with the nitrogen level in the fertilizer practice.

We now face the possibility of a demand for crop varieties adapted to a high soil nitrogen level, and in developing new varieties for this objective the plant breeder will need to give consideration to many characters. Some of the more important characters are disease resistance, maturity, lodging, keeping quality, nutritional value, yield, etc. Breeding material should be tested in the segregating generations for response to different nitrogen levels before the bulk of the plants are discarded on other criteria. Selection nurseries should be established on soils heavily fertilized with nitrogen comparable to the conditions under which the new variety is expected to be grown.

It is a long-time program but a great deal can be done immediately by testing existing new improved and commercial varieties for their growth responses and qualities at different nitrogen levels.

THE VALUE OF FARM UNIT TRIALS ON NITROGEN UTILIZATION

By J. C. McAmis, *Tennessee Valley Authority*

The influence of the application of nitrogen fertilizers goes far beyond the resulting increases in yield of crops; the whole farm economy is influenced; the management of the soil, the kinds of crops that will be grown, the livestock, their health and vigor, farm labor and its efficiency. The total effect may be good or ill, depending not alone upon the amount of nitrogen used but upon the way in which it is used in the farm program.

The war brought about the necessity for vastly increased amounts of nitrogen compounds. New plant capacity had to be built. These plants will be available for use after the military needs are over. The use of the product of these plants is the subject of this conference; thus the war affects agriculture. There also is the reverse relationship. If agriculture can make good use of the products of these plants and if the plants can be kept in operating condition as a result of use, the Nation will be to that extent better prepared for whatever the military requirements may be after the current conflict. Idle plants and men cannot maintain a high degree of efficiency. It ought to be possible for agriculture to make good use of the products and keep the plants as well as the operating personnel ready and fit for an emergency.

Agronomists naturally want to test the kind of product which they think their farmers can get. This plant can produce quantities and kinds of products that farmers and agronomists want. Naturally, engineers and agronomists need to get together in making the decision as to the most promising forms of nitrogen. Engineers need to know the results of careful scientific and practical testing. Agronomists need to know what forms of nitrogen can be produced and delivered to the farms most economically. Along with adequate supplies of different forms of nitrogen will come reliable figures as to cost of production under practical operating conditions which will enable a balance to be struck between cost and value.

If adequate quantities of commercial nitrogen are used, in whatever suitable form it can be delivered to the farmer at the cheapest price, and applied to the parts of the farm which are suitable for intensive and maximum production of grain and vegetable crops without injury to the land, we will then not speak of nitrogen as a burden but as a blessing.

In the Tennessee Valley there are thousands of farms where the operating program for several years past is a matter of record. Here the soils and their characteristics have been mapped and, to a large degree, their adaptability determined. If these farms are representative of those in the rest of the United States, suitable nitrogen fertilizers (properly supplemented with other elements) can be used in very large quantities—perhaps as much as may be available after the war. Heretofore, when nitrogen was scarce, it was important to get the maximum crop production per unit of nitrogen; when nitrogen gets plentiful, it becomes important to get the maximum production per acre of land suitable for intensive production. The value, effect, and best methods of use of nitrogen in this situation must be determined, through testing on the whole farm as a unit and on many farms.

STUDENT SECTION ESSAY CONTEST

THE Committee on Student Sections of the American Society of Agronomy has agreed that it is undesirable to continue the essay contest during the present emergency. It is the hope of the Committee that it may be possible to resume this worthwhile activity immediately after the end of the war. Announcement will be made as soon as the contest can be arranged for in the future.

NEWS ITEMS

SIR JOHN RUSSELL retired September 30 last under the age limit as Director of the Rothamsted Experiment Station. The Station will attain its one hundredth anniversary this year.

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DOCTOR THEODORE DYKSTRA of the Bureau of Plant Industry and Doctor WALTER C. LOWDERMILK, Chief of the Division of Research in Soil Conservation, arrived in Chunking December 10th. They will be joined later by a corps of about 30 American specialists to assist in modernization of agricultural methods in China.

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FREDERICK D. RICHEY of Ashville, Ohio, was appointed January 7 in the Division of Cereal Crops and Diseases of the U. S. Bureau of Plant Industry, with headquarters at Knoxville, Tenn. Mr. Richey will act as coordinator for the regional corn improvement program in the South, and direct the state corn program cooperative between the Tennessee Agricultural Experiment Station and the U. S. Dept. of Agriculture.

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THE 1943 VICTORY BOOK CAMPAIGN is appealing for books of all types, both fiction and nonfiction, for our armed forces. The American Library Association, The American Red Cross, and the United Service Organizations are sponsoring the effort. Local libraries are serving as receiving centers. Special emphasis is being placed on this campaign for the period of January 5 to March 5.

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THE NEW YORK TIMES recently carried an account by its Chungking correspondent of the use that is being made of material

from about 40 scientific journals, including this JOURNAL, and other publications now being microfilmed and sent to China. Arrangements for including this JOURNAL in the service were made by the Division of Cultural Relations of the State Department.

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SULFURIC ACID SEED TREATMENT OF BEACH PEA, *LATHYRUS MARITIMUS*, and SILVERY PEA, *L. LITTORALIS*, TO INCREASE GERMINATION, SEEDLING ESTABLISHMENT, AND FIELD STANDS[1]

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BEACH pea, *Lathyrus maritimus* (L) Bigel., commonly found along sandy beaches of the Northern Hemisphere and around the Great Lakes (1, 10),[3] and silvery pea, *L. littoralis* (Nutt.) Endl., found along the sea coast of Washington, Oregon, and California (4, 6), are valuable plant species for the revegetation and stabilization of marine sand dunes. Recognition of this is indicated by the Soil Conservation Service in a publication (8) discussing sand dune stabilization undertakings near the mouth of the Columbia River in Oregon. With increasing knowledge of these plants, needs have developed for seed, especially by public agencies engrossed in marine sand dune stabilization programs.

Seed of these two species has been limited. Production by native stands has been erratic and the cost of collection has been high. Seed is being produced in government nurseries, but problems in germination, establishment, and culture have been encountered that must be solved before seed can be produced at reasonable cost. Prompt, uniform, and high percentage of germination, if attainable, would facilitate production of seed in nurseries or production of vegetal cover for erosion control in areas where these species are adapted.

Recognizing the work of many authors concerning seed treatment to increase germination of leguminous seeds (7, 9, 12), a series of tests with several seasons' collection of both species were begun to determine the effect of sulfuric acid seed treatment on (a) germina-

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture. Received for publication April 23, 1942.

[2]Nursery managers respectively of the Pullman, Wash.; Astoria, Ore.; and Bellingham, Wash., units of the Nursery Division, Soil Conservation Service. The authors wish to express their appreciation to Dr. A. L. Hafenrichter, Chief, Regional Nursery Division, Soil Conservation Service, Pacific Region, for valuable suggestions and criticisms during the prosecution of this work and in the preparation of the manuscript.

[3]Figures in parenthesis refer to "Literature Cited", p. 190.

tion under laboratory conditions, (b) seedling establishment in soil in the greenhouse, and (c) stands from field plantings (2, 3).[4]

METHODS AND PROCEDURE

Seeds were collected from native stands along the coast of northwestern Oregon. Threshing was done by hand, followed by mill cleaning, and common warehouse storage in cloth bags. Sulfuric acid (concentrated) treatment at 68° to 71° F was in accordance with accepted technics for such work. After treatment and washing, seeds were subjected to a 5% solution of bicarbonate of soda for several minutes, subsequently rewashed, and dried. Treated seeds were stored in paper envelopes at room temperature. Germination tests were made between moist paper towels in paraffined pie-plates and germination was at room temperature. Each test included from 97 to 211 seeds distributed among two germinations. A seed was classed as germinated if it had developed a distinct radicle which protruded from the seedcoat. No effort was made to differentiate between weak abnormal sprouts and healthy normal ones because data were taken so frequently as to practically mask any differences which might be expected to occur.

Seedling emergence and establishment tests were made on the basis of duplicate lots of 100 seeds each in soil in the greenhouse at an average temperature of 65° F. Temperatures varied between 42° and 86° F. A seedling was considered established if it remained alive and healthy 6 days after emergence.

Trials to determine actual field stands were made near Warrenton, Ore., under conditions similar to those where large-scale plantings appear necessary for marine sand dune stabilization. Counted lots of from 500 to 1,000 seeds of each trial were hand planted to an average depth of 1 inch. Beach pea was planted July 16, 1938, and silvery pea, August 16, 1938. Stand percentages, indicated by live healthy seedlings, were made weekly for a period of 94 days for the former and 63 days for the latter species.

RESULTS AND DISCUSSION

GERMINATION IN GERMINATORS

Germination can be increased with sulfuric acid seed treatment (Tables 1 and 2). A maximum germination of 90% was obtained with beach pea after a 40-minute treatment and of 86% with silvery pea after a 50-minute treatment, as evidenced by averaged results from all seed lots after 12 to 14 days in the germinator. Untreated control showed an average germination of 35 and 13%, respectively.

There was considerable variation in germination between individual seed lots. This is especially apparent for beach pea (Table 1). Several variables may have contributed toward this variation, i.e., (a) variations in seed due to seasonal conditions, (b) mechanical injury due to threshing, and (c) age of seed before treatment and germination trials.

Assuming there was no error in sampling, the effect of seasonal variations is apparent in beach pea by comparing the germination of the control lots (13 and 27%) for 1935 and 1937 seed, respectively. In this case both mechanical injury and age of seed may be considered as common factors since the threshing and handling was done

[4]The present work was initiated before these trials were reported.

similarly and since the ages of the seeds before germination trials were reasonably comparable, 227 and 203 days, respectively. The seed was collected from the same source.

Mechanical injury to seed before acid treatment was not determined except in one instance, the results of which are included later in this report. It is assumed that mechanical injury in all lots studied was comparable since seed was threshed and handled in the same manner in each case.

Variation in results due to age of seed is easily verified for beach pea by referring to germination of untreated controls (Table 1), and comparing the 1935 and 1937 lots with the 1935a and 1936 lots. The latter two lots being 910 and 577 days old, respectively, before germination tests were started gave much higher percentages of germination in untreated controls than the former two lots whose ages were 227 and 203 days. The 1935 and 1935a lots are strictly comparable, being lots from the same collection, except that the former was 227 and the latter 910 days old before germination trials were started. In this case, germination of untreated controls after 12 to 14 days was 13 and 50%, respectively, which indicates that aging seed of this species improved seed germination. This does not agree with the findings of Dinnis and Jordan (3) who have indicated that 17 months of dry storage did not show appreciable change in the percentage of hard seed in this species. The effect of aging in reducing hard seed content for beach pea was not apparent in the controls with silvery pea (Table 2).

Improvement in germination through aging has been reported by Huntamer (5) for seeds of Indian rice grass, *Oryzopsis hymenoides*. In this case, aging was noted as being particularly important with respect to removing embryo dormancy. Although dormancy due to mechanical restraint of the seed coat was also indicated, it was not pointed out that aging had any effect in reducing this.

Lute (7) brings out the relationship between storage and increasing permeability of naturally impermeable alfalfa seed. Sonavne (11) indicates that certain leguminous seeds having high percentages of hard seeds when tested after harvest show a steady and fairly rapid increase in permeability with aging.

Although variation in germination results for different seasons' collections and for seed of different age was exhibited in untreated controls, germination after proper sulfuric acid seed treatment was increased to about the same actual germination percentage in all lots. For instance, after a 40-minute acid seed treatment actual germination of 88, 88 and 94% was obtained for 1935, 1936, and 1937 seed lots, respectively, while the controls gave 13, 49, and 27% germination. For silvery pea, after a 50-minute acid seed treatment, actual germination of 88 and 85% was obtained for 1935 and 1937 seed lots, while untreated controls gave 12 and 13%, respectively. It appears that the different seed lots had approximately the same germinating capacity under proper conditions of acid seed treatment irrespective of seasonal variation or age of seeds.

The number of sound hard seeds remaining in the trials can be used as an index to the efficiency of acid treatment. Acid treatment

TABLE 1.—*Effect of different periods of sulfuric acid seed treatment on the germination of four lots of beach pea, Lathyrus maritimus.*

Seed lot*	Minutes of acid treatment	No. of seeds in test	Germination after 12 to 14 days		Ungerminated, seeds after 12 to 14 days			
					By seed lot		Average four lots	
			By seed lot, %	Av. four lots, %	Rotted %	Hard %	Rotted %	Hard %
1935	Control	199	13		5	85		
1935a	Control	201	50		5	46		
1936	Control	199	49		10	41		
1937	Control	201	27	35	7	67	7	60
1935	10	104	59		1	41		
1935a	10	201	63		4	33		
1936	10	201	59		7	33		
1937	10	200	63	61	6	32	5	35
1935	20	97	87		4	7		
1935a	20	—	—		—	—		
1936	20	202	87		5	9		
1937	20	200	88	87	3	10	4	9
1935	30	130	78		13	2		
1935a	30	—	—		—	—		
1936	30	192	87		5	5		
1937	30	200	95	87	2	3	7	3
1935	40	118	88		7	6		
1935a	40	—	—		—	—		
1936	40	202	88		5	8		
1937	40	200	94	90	4	2	5	5
1935	50	108	92		6	3		
1935a	50	200	88		6	6		
1936	50	200	83		11	6		
1937	50	199	92	89	4	4	7	5
1935	60	120	91		7	3		
1935a	60	198	73		21	5		
1936	60	200	76		13	10		
1937	60	200	82	81	13	5	14	6
1935	70	104	81		9	10		
1935a	70	200	80		18	3		
1936	70	198	44		47	8		
1937	70	201	80	71	14	6	22	7
1935	80	118	85		11	3		
1935a	80	197	51		43	5		
1936	80	200	55		40	6		
1937	80	201	69	65	20	12	29	7
1935	90	126	67		29	3		
1935a	90	198	40		50	10		
1936	90	200	65		28	7		
1937	90	200	65	59	27	8	34	7

TABLE 1.—*Concluded.*

Seed lot*	Minutes of acid treatment	No. of seeds in test	Germination after 12 to 14 days		Ungerminated seeds after 12 to 14 days			
			By seed lot %	Av. four lots %	By seed lot		Average four lots	
					Rotted %	Hard %	Rotted %	Hard %
1935	100	150	64		26	12		
1935a	100	192	26		67	5		
1936	100	199	36		58	6		
1937	100	201	29	39	65	7	54	8

*Seed was collected approximately August 1 of the year indicated. Periods of dry storage before and after seed treatment were 225 and 2,900 and 10, 540, and 37, and 180 and 23 days for the 1935, 1935a, 1936, and 1937 seed lots, respectively.

reduced the percentage of hard seeds in all lots, irrespective of treatment, season, or age for beach pea. For silvery pea, a consistently greater percentage of hard seeds were reduced in all trials of the older seed lot. Even the longer treatments were not successful in reducing the hard seeds below about 6 and 10% for beach and silvery pea, respectively, which is the average in each case for all treatments longer than 10 minutes. This may be considered as a very high degree of effectiveness. A 10-minute treatment reduced some but not all of the hard seeds, as there still remained an average of 35 and 20% hard seeds for the two species in the same respective order as mentioned above. Untreated controls, however, retained an average of 60 and 74% hard seeds at the end of the trials.

Although the number of hard seeds were reduced to practically a common percentage for all seed lots of both species in treatments longer than 10 minutes, highly variable germination results were obtained from the different treatments. The number of ungerminated rotted seeds remaining in the germination trials at their termination may be taken as an indication of injury to seeds in the longer periods of acid treatment and indicate a partial cause of the varying results with different degrees of acid treatment. For both species, ungerminated rotted seeds comprised only from 5 to 10% of the trials in treatments of from 10 through 50 minutes. For treatments of longer duration, a gradual increase in the number of ungerminated rotted seeds was obtained, which clearly indicates injury due to acid treatment of long periods. For these species, there appears to be a rather wide range of treatments—20, 30, 40, and 50 minutes—which (a) effectively eliminates the hard seed content, (b) does not cause appreciable injury, and (c) allows a considerable increase in germination as compared with untreated controls (Tables 1 and 2). The optimum treatment for recommended use lies somewhere within this wide range of successful treatments, but for practical recommendations further trials more nearly approaching use conditions are necessary. These trials are discussed in the following sections.

TABLE 2.—*Effect of different periods of sulfuric acid seed treatment on the germination of two lots of silvery pea, Lathyrus littoralis.*

Seed lot*	Minutes of acid treatment	No. of seeds in test	Germination after 13 days		Ungerminated seeds after 13 days			
					By seed lot		Average two lots	
			By seed lot %	Av. two lots %	Rotted %	Hard %	Rotted %	Hard %
1935	Control	199	12		8	80		
1937	Control	196	13	13	17	68	13	74
1935	10	199	75		11	14		
1937	10	191	65	70	8	26	10	20
1935	20	199	87		8	5		
1937	20	200	75	81	11	14	10	9
1935	30	201	89		8	4		
1937	30	200	80	84	10	10	9	7
1935	40	200	88		9	4		
1937	40	201	69	78	11	20	10	12
1935	50	200	88		10	2		
1937	50	211	85	86	8	8	9	5
1935	60	200	83		14	4		
1937	60	199	68	75	16	16	15	10
1935	70	197	76		18	6		
1937	70	200	55	65	19	27	19	16
1935	80	195	70		25	4		
1937	80	200	58	64	20	23	23	13
1935	90	195	64		29	5		
1937	90	199	54	59	30	15	30	10
1935	100	202	62		36	3		
1937	100	200	46	54	39	16	37	9

*Seed was collected approximately August 1 of the year indicated. Periods of dry storage before and after seed treatment were 900 and 10 and 180 and 23 days for the 1935 and 1937 seed lots, respectively.

Data presented in Tables 1 and 2 do not give a complete picture of the effect of proper acid seed treatment on germination. The effect of treatment on the rapidity of germination is also important and this is shown in Figs. 1 and 2 for beach and silvery pea, respectively. Germination after the most favorable acid seed treatment was greater at all times during the course of the trials than for that of untreated controls for both species.

SEEDLING ESTABLISHMENT FROM PLANTINGS IN THE GREENHOUSE

Seedling establishment data from greenhouse plantings for both species are summarized in Fig. 3. As expected, improvement by favorable acid treatment is not as pronounced when using seedling establishment as a criterion of results as it is when seed germination is used to measure improvement. Average seedling establishment of

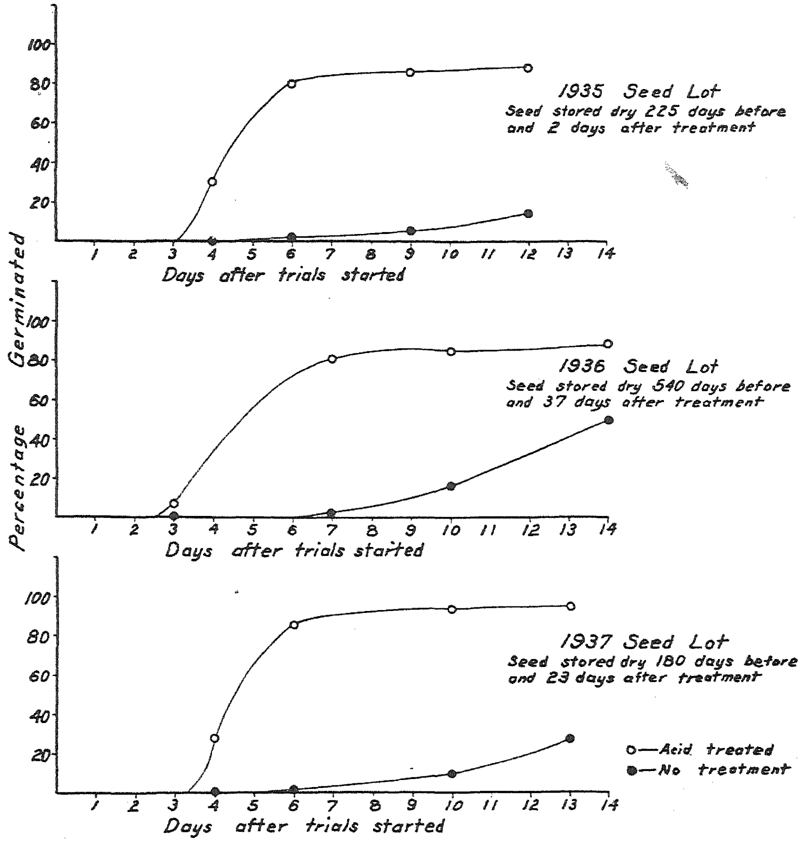

FIG. 1.—Course of germination percentage from three seed lots of beach pea, *Lathyrus maritimus*, with and without a 40-minute sulfuric acid seed treatment.

all lots after 22 to 24 days was increased over the average for the controls in 10-, 20-, 30-, and 40-minute treatments with beach pea. A definite maximum was indicated with both 10- and 20-minute treatments which gave 46% establishment as compared with 21% for the untreated control. Similar results were obtained 22 days after greenhouse plantings with silvery pea, except that the average maximum acid treatment was 20 minutes and showed establishment of 42% as compared with only 3% for the untreated control. Greenhouse tests were concluded after 34 days.

Seedling emergence data, although not presented, showed similar results. The average increase in emergence in all lots for each treatment fell between that for germination results in germinators and seedling establishment in greenhouse plantings, as would be expected.

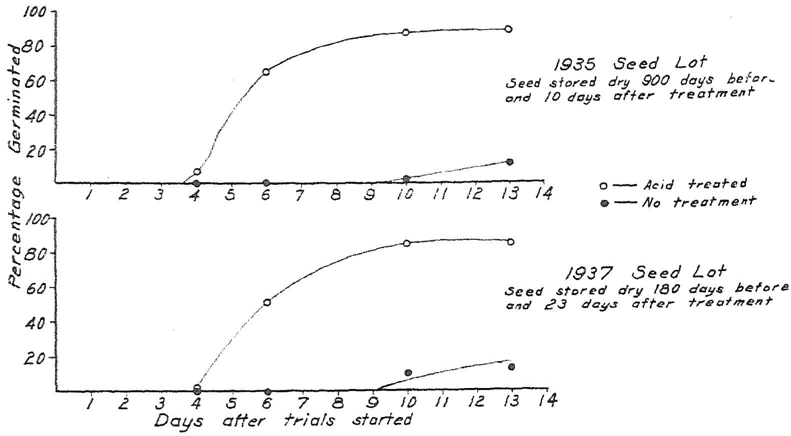

FIG. 2.—Course of germination percentage from two seed lots of silvery pea, *Lathyrus littoralis*, with and without a 50-minute sulfuric acid seed treatment.

ACTUAL STANDS IN FIELD PLANTINGS

Final recommendations for acid seed treatment should be based on results of trials under actual field conditions. Field plantings were made as described and, although not comparing exactly with recommended large-scale field use, they were sufficiently similar to provide a basis for definite recommendations (Tables 3 and 4). It is apparent that acid seed treatment of short duration was beneficial in obtaining satisfactory stands. Maximum percentage stand is indicated for acid seed treatment of 20 to 30 minutes for beach pea and silvery pea, respectively. Treatments for periods of 60 minutes and longer for beach pea and of 40 minutes and longer for silvery pea were injurious, resulting in increasingly diminished field stands with increasing periods of acid treatment.

The course of stand percentage from seeds treated 20 minutes with acid and from untreated seeds during the total period observations were made is shown in Figs. 4 and 5 for beach pea and silvery pea, respectively.

In the case of beach pea, treated seed of both the 1936 and 1937 collections produced a higher percentage stand than did the control 17 days after planting and at all subsequent intervals up to 94 days (Fig. 4). The 1935 seed lot of silvery pea showed an increase in stand percentage at all periods of observation from 21 to 63 days after planting. The increase was more pronounced during the shorter periods after planting (Fig. 5). For the 1937 seed lot, an increase in stand percentage is shown 21 and 36 days after planting acid-treated seed, but 27, 49, 56, and 63 days after planting, a slight diminution in stand is shown as compared with untreated controls (Fig. 5).

The field plantings reported were made during the driest period of the year, which, according to 52 years of U. S. Weather Bureau records, is the months of June, July, August, and September. Plant-

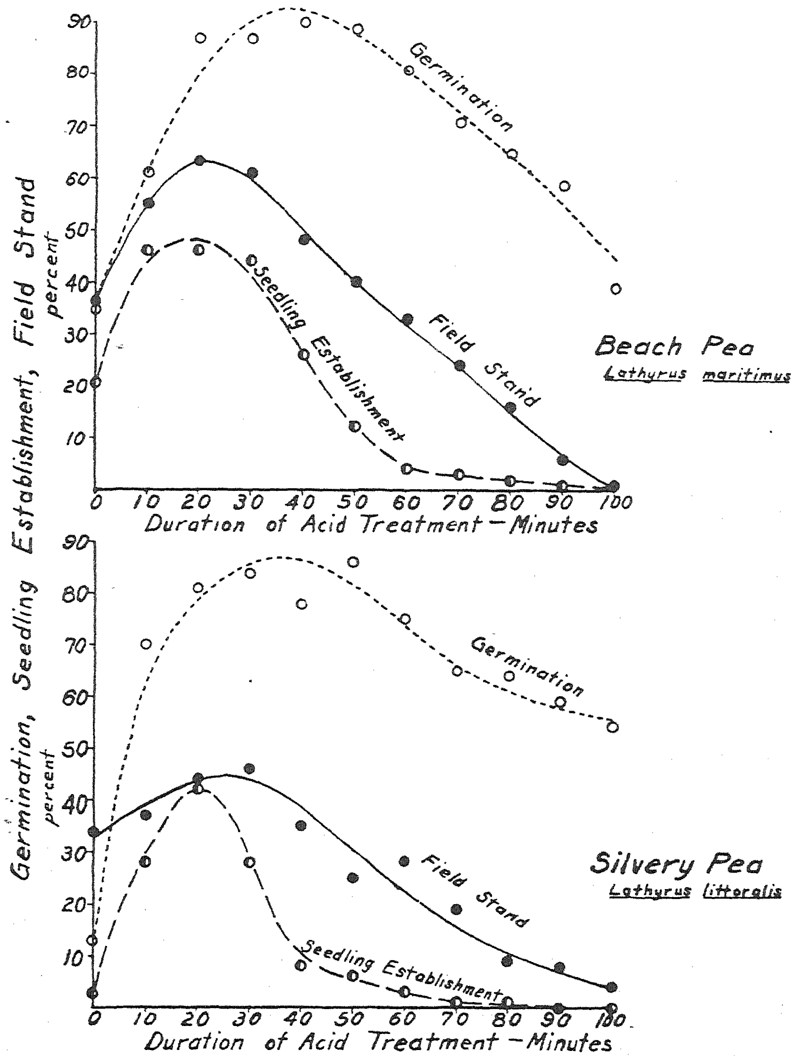

FIG. 3.—Germination in germinators, seedling establishment in the greenhouse and stands obtained in field plantings with beach pea, *Lathyrus maritimus*, and silvery pea, *L. littoralis*, as influenced by sulfuric acid seed treatment.

ings would not ordinarily be made during this period, but the results obtained in these trials, together with greenhouse and germinator results, indicate the relationship between acid seed treatment and

TABLE 3.—*Effect of different periods of sulfuric acid seed treatment on stands obtained in the field plantings of beach pea, Lathyrus maritimus, from three different seed lots.**

Seed lot†	Minutes of acid treatment	Total stand after 38 days	
		By seed lot %	Av. three lots %
1935	Control	46	
1936	Control	36	
1937	Control	27	36
1935	10	57	
1936	10	45	
1937	10	63	55
1935	20	—	
1936	20	72	
1937	20	53	63
1935	30	—	
1936	30	60	
1937	30	62	61
1935	40	—	
1936	40	50	
1937	40	45	48
1935	50	40	
1936	50	42	
1937	50	39	40
1935	60	30	
1936	60	44	
1937	60	25	33
1935	70	38	
1936	70	13	
1937	70	21	24
1935	80	12	
1936	80	18	
1937	80	19	16
1935	90	6	
1936	90	6	
1937	90	5	6
1935	100	0	
1936	100	2	
1937	100	1	1

*1,000 seeds in test.

†Seed was collected approximately August 1 of the year indicated. Periods of dry storage before and after seed treatment were 900 and 167, 540 and 165, and 180 and 165 days for the 1935, 1936, and 1937 seed lots, respectively.

results expected from ordinary field plantings. Temperature relationships may be eliminated as an influencing factor in the field trials reported because fluctuations are slight in the area. For instance, the 1938 average temperature for the months of July, August, September, and October was 58.7° F with a maximum of 78° F and

TABLE 4.—*Effect of different periods of sulfuric acid seed treatment on stands obtained in field plantings of silvery pea, Lathyrus littoralis, from two different seed lots.*

Seed lot*	Minutes of acid treatment	No. of seeds in test	Total stand after 36 days	
			By seed lot %	Av. two lots %
1935	Control	600	41	
1937	Control	900	26	34
1935	10	500	44	
1937	10	1,000	29	37
1935	20	600	56	
1937	20	1,000	31	44
1935	30	600	63	
1937	30	1,000	28	46
1935	40	600	49	
1937	40	1,000	21	35
1935	50	600	38	
1937	50	1,000	12	25
1935	60	600	29	
1937	60	700	16	28
1935	70	600	21	
1937	70	575	16	19
1935	80	600	13	
1937	80	600	5	9
1935	90	500	11	
1937	90	600	5	8
1935	100	600	5	
1937	100	600	2	4

*Seed was collected approximately August 1 of the year indicated. Periods of dry storage before and after seed treatment were 900 and 167 and 180 and 165 days for the 1935 and 1937 seed lots, respectively.

a minimum of 44° F. The mean annual temperature, including 52 years of records, is 50° F. The fluctuations of recorded temperatures in the greenhouse trials were greater than those for the field trials. The critical 30-day period after planting in the field was probably unfavorable only insofar as moisture was concerned.

As the results obtained from direct field plantings under unfavorable moisture conditions favor acid seed treatment and since results from germination trials and seedling establishment trials under more favorable conditions both affirm these results, it is reasonable to assume that in field plantings during more favorable periods, even larger improvement in stand percentages than shown in Tables 3 and 4 can be expected.

Fig. 3 presents graphically a comparison between germination, seedling establishment, and field stands as influenced by different acid

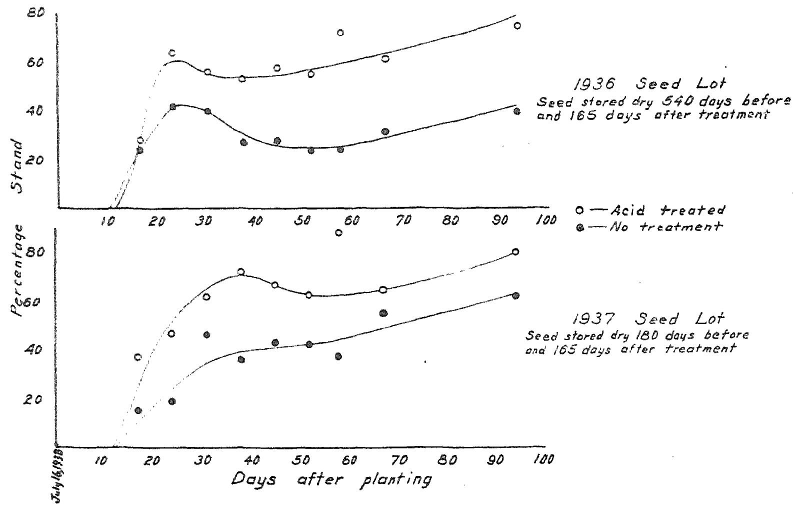

FIG. 4.—Course of stand percentage from two seed lots of beach pea, *Lathyrus maritimus*, with and without a recommended 20-minute sulfuric acid seed treatment.

seed treatments. The figures represent averages of all seed lots used in the trials. If recommendations were based on germination results only, the correct acid seed treatment might not be used. However, recommendations could be safely made on the basis of both greenhouse trials and of trials in the field. In this case the best acid seed treatment for beach pea is about 20 minutes and for silvery pea somewhere between 20 and 30 minutes. On the basis of germination

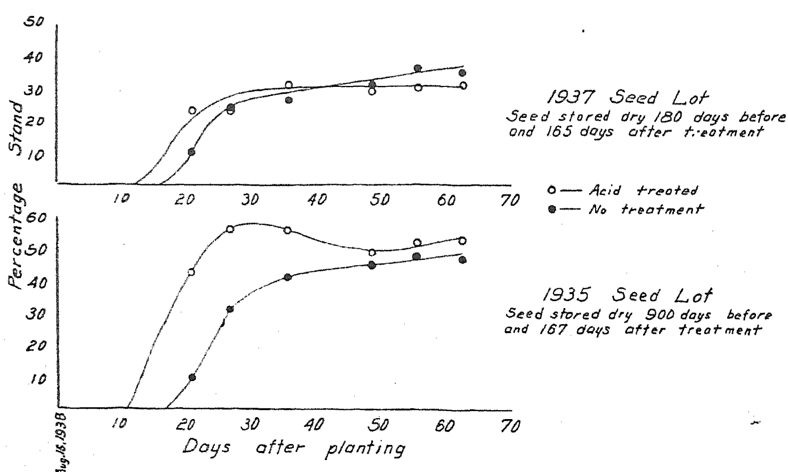

FIG. 5.—Course of stand percentage from two seed lots of silvery pea, *Lathyrus littoralis*, with and without a recommended 20-minute sulfuric acid seed treatment.

trials reported by Dinnis (2), a standard recommendation for practical use of 1½ hours of acid treatment was made. It is obvious from the work reported that this recommendation, based completely on germination results, would be entirely too severe for seed planted directly in the field.

ECONOMY OF TREATMENT

No cost data on acid treatment of seed in quantities have been obtained. Meginnis (9) indicates a cost of from 2 to 5 cents per pound for considerably longer periods of similar acid treatment of black locust seed. A cost of 5 cents per pound for acid seed treatment may be assumed for the species used in the present trials. Cost figures for beach and silvery pea seed obtained to date are 88 cents and $2.32 per pound, respectively. The respective recommended seeding rates for these two species are 8 and 14 pounds per acre in seedings for nursery production and 12 and 18 pounds per acre in seedings for erosion control. Using these figures and the cost data mentioned, a saving in seed cost per acre of 39% for beach pea and 24% for silvery pea can be made for both types of seedings if recommended sulfuric acid seed treatments are used. These savings will amply justify the added expense of satisfactory seed treatment.

GENERAL DISCUSSION

The writers believe that methods of mechanical seed scarification could be used to advantage for these species. Machine threshing and cleaning, which would be required in large-scale use of the species, might possibly fulfill scarification requirements. Often, in seed treatment recommendations, the actual scarification brought about by handling seed with machinery is overlooked and a tendency might exist to treat seed too severely.

Frequently, many seeds are injured by acid treatment due to breaks in the seed coat, indistinguishable to the naked eye, which may have allowed penetration of acid and injury to the embryo. To determine the extent of such possibilities, a sample of the 1937 lot of silvery pea was examined under a 40X magnification. Of 100 seeds examined, 19% had seed coats which would undoubtedly allow the injurious penetration of acid. The remaining 81% were sound, unbroken seeds. Acid treatment to increase germination should be used when only a relatively small percentage of the seed population shows cracks or heavy abrasions. If a large number have broken seedcoats, it is probable that some mechanical method of scarification will be more satisfactory, if any treatment is necessary.

In treating large quantities of seed of these two species with acid, it is recommended that preliminary tests be made. By a comparison of a few preliminary tests with and without acid treatment, with the complete data herewith reported, reliable recommendations can be made for any seed lot in a comparatively short time.

SUMMARY

Beach pea, *Lathyrus maritimus*, and silvery pea, *L. littoralis*, are important legumes being used in secondary plantings to control shifting marine sand dunes along the Oregon coast and have considerable possibilities for use elsewhere. Seed has been limited and costly due to erratic production from native stands and due to cultural problems in nursery production. To get greater efficiency from available seed, tests have been conducted to determine the effect of sulfuric acid seed treatment on germination, seedling establishment, and field stands.

Several seed lots of different years' collections with different periods of dry storage before and after treatment have been considered. The trials indicate a definite advantage for proper sulfuric acid seed treatment. The seeds used responded to an optimum acid treatment of 20 minutes for beach pea and 30 minutes for silvery pea. Increased efficiency from properly treated seed will allow a lower seeding rate. A saving in seed cost per acre of 39% for beach pea and 24% for silvery pea can be made in both plantings for seed production or for erosion control if satisfactory sulfuric acid seed treatment is used.

Periods of dry storage before and after seed treatment, although as long as 900 and 167 days, respectively, were not strikingly influential in altering results, yet definite information was obtained which indicates that long periods of dry storage decrease the hard seed content of beach pea and consequently cause an improvement in germination of untreated seed.

In treating large seed lots of these species with acid to promote efficiency in nursery seed production or to increase immediate effectiveness in plantings for erosion control, it is suggested that laboratory tests of germination after acid treatment be conducted on each large seed lot in question. With the information presented, it will then be possible to adjust results to conform to those expected from direct field plantings and acid treatment recommendations for the large lots can be made.

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A COMPARISON OF THE FIRST YEAR'S ROOT PRODUCTION OF SEVEN SOUTHERN GRASSES ESTABLISHED FROM SEED[1]

GLENN W. BURTON[2]

THAT a knowledge of the root distribution of various species is helpful in explaining and predicting their environmental response has been well established. Although many grass root studies have been made, little work has been done with southern grasses.

Laird[3] studied the root systems of centipede, Bahia, Dallis, blue couch, Bermuda, St. Lucie, and St. Augustine grass when grown under several types of management on the deep sandy soils of Florida. In his studies all grasses were established vegetatively and many of the data were obtained from 4-year-old sods. He reported that the roots of all species extended to a depth of 6 to 8 feet and that Bahia grass produced a better root system than the other grasses studied.

Single-row plots spaced 3 feet apart and replicated four times were seeded to the eight grasses listed below on April 28, 1939. The A horizon of the Tifton sandy loam in which these grasses were grown extended to a depth of 9 inches. The B horizon included the layer from 9 to 36 inches below the surface. Weather conditions favored seed germination and the following dates of emergence were recorded: Common Bahia grass, *Paspalum notatum* Flugge., May 7; *Paspalum malacophyllum* Trin., May 7; Paraguay Bahia grass, *Paspalum notatum* P. I. 121415, May 11; vasey grass, *Paspalum urvillei* Steud., May 13; Dallis grass, *Paspalum dilatatum* Poir., May 15; woolly-finger grass, *Digitaria eriantha* Steud., P. I. 77998, May 25, and carpet grass, *Axonopus affinis* Chase, June 5. Since the Bermuda grass, *Cynodon dactylon* (L.) Pers., seed germinated very poorly and later than the other species, Bermuda grass was not included in the root studies made in December. In order to eliminate weed competition, the entire test was kept free of weeds throughout the summer and fall. The grasses were neither cut nor grazed during the growing season.

In December 1939, the extent and distribution of the root system of each species were determined. The root samples were obtained by digging around 3 sides of the row and cutting out a prism of soil 5½ by 9 inches to the desired depth. After the prisms were trimmed down and marked off at 4-inch levels (Fig. 1), they were cut into 4 by 5½ by 9 inch blocks of soil from which the roots were washed.

[1]Cooperative investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the Georgia Coastal Plain Experiment Station, and the Georgia Experiment Station at Tifton, Ga. Received for publication October 9, 1942.

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[3]LAIRD, A. S. A study of the root systems of some important sod-forming grasses. Fla. Agr. Exp. Sta. Bul. 211. 1930.

All stems, stolons, and rhizomes were carefully removed from the roots in the upper levels. The samples of roots for each 4-inch section were then dried, weighed, ashed, and reweighed in order to correct for the small particles of soil that could not be removed by washing. A summary of these corrected weights are presented in Tables 1 and 2.

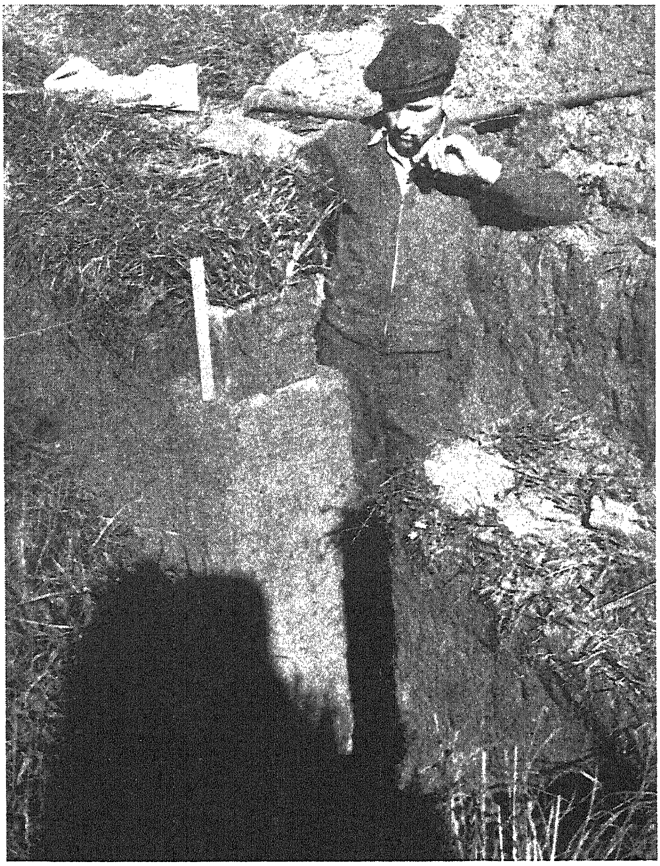

FIG. 1.—A plot of Bahia grass prepared to facilitate obtaining the 4-inch sections and the $5\frac{1}{2} \times 9 \times 44$ inch prisms of soil from which the root samples shown in Fig. 2 were obtained.

Three replications were sampled in duplicate to a depth of 16 inches. The variance of the mean yields from these samples was calculated and the significance of F and the least significant mean difference at the 5% level are included in Table 1. Only one replication was sampled in duplicate to a depth of 44 inches, the maximum depth reached by any of the grasses studied. The results from this replication appear in Table 2. Representative topgrowth deter-

FIG. 2.—The tops and roots found in December 1939 in a 5½ × 9 × 44 inch prism of soil taken from plots of seven grasses, from left to right, *Paspalum notatum*, *Paspalum notatum* (Paraguay) P.I. 121415, *Paspalum dilatatum*, *Paspalum malacophyllum*, *Paspalum urvillei*, *Digitaria eriantha* P.I. 77998, and *Axonopus affinis*.

minations could not be made in this study because some of the plots were accidentally grazed by a tenant's cow in December.

The marked differences in the root growth made by seven grasses in their first season from seed are shown in Fig. 2 and Tables 1 and 2. Considering the root weights for the four sections from 0 to 16 inches presented in Table 1, it is apparent that the two Bahia grasses,

TABLE 1.—*The dry weight in grams of roots found in the first 16 inches of soil in December 1939 under 100 square inches of sod of seven grasses seeded April 28, 1939.**

Soil level, inches	*Paspalum notatum*	*Paspalum notatum* (Paraguay)	*Paspalum dilatatum*	*Paspalum malacophyllum*	*Paspalum urvillei*	*Digitaria eriantha*	*Axonopus affinis*	Mean root weights all grasses
0–4......	23.76	17.79	12.80	10.71	7.17	7.62	10.38	12.89
4–8......	11.95	13.42	6.60	4.80	2.39	4.12	3.32	6.66
8–12.....	4.72	6.12	1.51	1.22	0.63	1.69	0.79	2.38
12–16.....	3.48	4.44	0.90	1.27	0.41	1.13	0.58	1.74
Mean.....	10.97	10.44	5.45	4.50	2.65	3.94	3.77	——

*Yields are the average of duplicate samples taken from three replications. F for grasses and soil levels exceeds the 1% point and for the grass × soil level interaction exceeds the 5% point. The least significant 5% mean difference for individual means (n = 3) = 4.65; for grass means (n = 12) = 2.33; and for soil level means (n = 21) = 1.76.

TABLE 2.—*The extent and distribution in grams of the roots in December 1939 under 100 square inches of sod of seven grasses seeded April 28, 1939.**

Soil level, inches	*Paspalum notatum*	*Paspalum notatum* (Paraguay)	*Paspalum dilatatum*	*Paspalum malacophyllum*	*Paspalum urvillei*	*Digitaria eriantha*	*Axonopus affinis*
0–4......	25.89	23.58	11.43	12.78	6.23	8.58	10.16
4–8......	17.23	17.58	4.08	5.98	1.73	3.57	2.30
8–12......	6.81	8.07	1.54	1.81	0.59	1.77	0.21
12–16......	5.21	5.56	1.08	1.06	0.35	1.28	0.22
16–20......	5.16	5.63	1.28	1.08	0.52	0.99	0.17
20–24......	5.81	5.04	0.87	1.12	0.35	0.74	0.20
24–28......	5.38	4.34	0.82	1.02	0.22	0.59	0.23
28–32......	4.41	3.70	0.63	1.17	0.11	0.67	0.12
32–36......	1.72	2.16	0.25	0.67	0.07	0.30	0.06
36–40......	0.58	0.29	0.10	0.09	0.03	0.22	——
40–44......	0.02	——	——	——	——	——	——
Total......	78.22	75.95	22.08	26.78	10.20	18.71	13.67

*Yields are the average of duplicate samples taken from one replication.

Paspalum notatum, produced a significantly greater quantity of roots than the other species in these soil layers. The significant differences between the mean root weights of the three upper soil levels and the significant grass × soil level interaction are worthy of note.

Since the determinations for Table 2 were not replicated, the interaction mean square was used as an estimate of the error variance. This procedure, when applied to the data for the soil levels from 0 to 16 inches in Table 2, led to the same conclusions concerning grasses and soil levels that were drawn from the analyses of Table 1. A similar analyses of the soil levels ranging from 16 to 36 inches (Table 2) indicated that the Bahia grasses exceeded the others in root weight below the 16-inch soil level. Although there was a gradual reduction in the mean root weights with depth, the mean root weights of all grasses for the soil layers occurring at depths of 16 to 32 inches did not differ significantly.

In total root production (Table 2) the Bahia grasses possessed nearly three times as much dry roots as any of the other grasses, four times as much as carpet grass, *Axonopus affinis*, and seven times as much as vasey grass, *Paspalum urvillei*. The roots of the Bahia grasses were coarser and the roots of *Paspalum malacophyllum* and *Digitaria eriantha* were finer than the roots of the other species studied. Since the relation between root diameter and efficiency of water absorption and translocation has not been established, the interaction of root diameter and total dry weights of roots can hardly be evaluated.

Although the maximum depth reached by the roots of these grasses did not differ greatly, differences in the distribution of their roots in the soil is worthy of note. Over three-fourths of the total roots produced by the two grasses known to be best adapted to low, wet areas, vasey and carpet grass, were found in the upper 8 inches of

soil. On the other hand, three fourths of the roots of the Bahia grasses occurred in the upper 20 inches of soil. Since these Bahia grasses produced a greater quantity of roots and since a higher percentage of those roots penetrated the lower soil layers, they might be expected to be better adapted to dry, sandy soils than the other species included in this study. Observations to date indicate that they are.

REACTION OF SOME VARIETIES AND STRAINS OF WINTER WHEAT TO ARTIFICIAL INOCULATION OF LOOSE SMUT[1]

I. M. Atkins[2]

DURING the period 1931 to 1939, inclusive, loose smut of wheat, caused by *Ustilago tritici* (Pers.) Rostr., caused an estimated annual loss in Texas of 454,000 bushels, or approximately 1.8% of the crop (7).[3] Since the major portion of the wheat crop is grown in the less humid sections of the state where loose smut is a minor factor in production, it is evident that the disease is of considerable importance in the more humid sections of central and north central Texas. In these areas loose smut often causes losses on individual farms of from 5 to 10%, which are sufficiently high to be of serious economic importance to the individual farmer. All commercial varieties now grown are very susceptible to the disease. Because of the economic importance of loose smut in central Texas and the need for information on sources of resistance, and in order properly to plan the wheat breeding program at Texas Substation No. 6, Denton, Tex., tests of varietal resistance by means of artificial inoculations were started in the spring of 1937.

MATERIAL AND METHODS

The method of inoculation used in this study was the partial vacuum spore-suspension method devised by Moore (5). The apparatus was modified slightly by using a larger inoculating chamber and two openings in the rubber stopper, so that two spikes instead of one could be inoculated at one time. In 1937 inoculations were made at three stages of maturity to determine the optimum stage of growth for inoculating. Other tests were made to determine the best time of day for inoculating. In later seasons, inoculation of four heads gave ample seed for testing the resistance of the variety.

The inoculum was prepared by collecting smutted heads from several varieties of wheat on the station and from a number of farms in this region. A composite of this smut was prepared and used throughout the season so that all varieties were inoculated with the same inoculum.

Inoculated seed was space planted, 2 to 3 inches apart in 10-foot nursery rows, the following season. The number of plants tested per variety ranged from 25 to 50 each season, although in a few instances poor stands reduced this number. In 1940 and 1941, the test was dusted with sulfur to reduce rust infection and allow normal growth of the plants.

The percentage of smut infection was computed from counts of smutted and smutfree culms in 1938. In all other seasons, the calculations were based on plant counts.

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[1]A report of cooperative investigations between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Texas Agricultural Experiment Station. Received for publication November 2, 1942.

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[3]Figures in parenthesis refer to "Literature Cited", p. 204.

EXPERIMENTAL DATA

PRELIMINARY TESTS OF INOCULATING TECHNIC

In 1937 a preliminary test was made to determine the optimum stage of growth at which to inoculate the plants. Varieties under test were inoculated at three stages, which for convenience may be called pre-anthesis, i.e., before any spikelets in the head had bloomed; mid-anthesis, when numerous spikelets in the center of the head were shedding pollen; and post-anthesis, after all spikelets had shed pollen. As an average of 36 varieties, ranging from resistant to highly susceptible types, the following results were obtained: Pre-anthesis, 33.0%; mid-anthesis, 27.7%; and post-anthesis, 18.7%. It appears from these results, which agree with those of Oort (6) using similar apparatus, that early to mid-anthesis is the most desirable time to inoculate plants, although inoculations can be made over a period of several days without greatly changing the results.

It is generally believed that natural infection by loose smut is markedly affected by atmospheric humidity and Tapke (9) has shown that such is the case. Humidity of the air would not be expected to be so important with artificial inoculation with the methods used in this study, but nevertheless it seemed desirable to have definite information on this point. The rapid changes that normally take place from morning to midafternoon under Texas conditions seemed to afford a good opportunity for a study of these relations. Accordingly, Red May wheat was inoculated at intervals of 1 to 2 hours during the day. At the same time, the relative humidity of the air was determined by means of a wet-bulb humidity apparatus. This indicates in a general way the atmospheric conditions following inoculations. The results obtained are given in Table 1.

TABLE 1.—*Loose smut infection obtained by artificial inoculation of Red May wheat at intervals during the day and humidity of the air at similar intervals, Texas Substation No. 6, Denton, Texas.*

Time of day	Relative humidity, %			Loose smut infection, %		
	1940	1941	Av.	1940	1941	Av.
7 a.m.	58	—	58.0	59.1	—	59.1
8 a.m.	52	73	62.5	67.9	50.0	59.0
9 a.m.	45	66	55.5	57.1	73.3	65.2
10 a.m.	48	53	50.5	16.7	44.4	30.6
12 noon	43	50	46.5	73.7	47.4	60.6
2 p.m.	38	41	39.5	71.9	50.0	61.0
4 p.m.	35	37	36.0	69.2	71.4	70.3

From the data obtained i[illegible] appears, as might be expected, that the humidity of the air has lit[illegible] influence on inoculation with a spore suspension under vacuum. [illegible]he very low infection for the 10 a.m. inoculation in 1940 is undo[illegible]tedly due to escape.

REACTION OF VARIETIES

Varieties tested for their relative susceptibility or resistance to loose smut included most of the commercially grown hard and soft winter wheat varieties and many of the more promising unnamed hybrid selections. Percentage infection for each variety in each of the 4 years, 1938 to 1941, inclusive, so far as they were tested, are given in Table 2, together with the average infection for the years tested. The averages, it should be noted, are not all strictly comparable one with another because of the rather marked differences in infection in different years and the fact that some varieties were not grown in all years.

The varieties are arranged in alphabetical order by market classes, although the classification of some of the hybrid strains is only tentative. Various factors contributed to lack of continuity of the data. Among these may be mentioned loss of stand owing to poorly developed seed following rust damage, loss of stand owing to dry weather in the fall, failure to inoculate the variety, and others. Some varieties which proved very susceptible in previous seasons were dropped from the 1941 test. New strains were added to the test each season.

Variation in the percentage of smut infection within varieties is very high in some instances. Some varieties known to be highly susceptible under natural field conditions have, for unknown reasons, consistently escaped artificial infection. Seasonal variability within varieties may be due to several causes. In early stages of the test the failure to select heads in the proper stage of maturity may have been a contributing factor. Failure to obtain a good vacuum in the apparatus with resulting lack of opportunity for infection may have occurred in some instances. Variability in the concentration of inoculum of various physiological races in different seasons may have contributed to the differences. During the past two seasons, the methods used have been improved and good infections have been obtained. Susceptible varieties are now rapidly being eliminated from the test.

The data indicate marked differences between varieties and that some varieties of each class, except the club wheats of which only two varieties were tested, are highly resistant. There is considerable variation between seasons, as previously mentioned, and since the inoculum was from local sources, quite different results might be obtained with inoculum from other areas. Additional tests therefore will be necessary before complete information is available.

All the varieties of hard winter wheat that are now grown commercially in the Great Plains area are susceptible. Blackhull and Ridit, which were resistant in early tests by Tapke (8), were highly susceptible in the present tests. Pawnee, a selection from the cross Kawvale × Tenmarq and developed cooperatively by the Kansas and Nebraska Agricultural Experiment Stations, was resistant throughout the 4-year period. This recently named variety is being increased for distribution in southeastern Nebraska. It appears to have inherited the loose smut resistance of Kawvale, and since it is well adapted to portions of the hard winter wheat region, it is suggested as one of the best sources of loose smut resistance for trans-

TABLE 2.—*Loose smut infection obtained from artificial inoculation in varieties and strains of winter wheat at Texas Substation No. 6, Denton, Tex., 1938–41.*

Variety or strain	C.I. No.	Loose smut infection, %				
		1938	1939	1940	1941	Av.
Hard Red Winter Wheat Varieties and Strains						
Akron selection	11660	3.4	0	0	0	0.9
Argentina Inst. Fito. No. 1051	—	—	—	—	10.0	10.0
Beloglina × Hussar	11513	6.7	—	53.3	—	30.0
Blackhull	6251	5.8	—	47.4	80.0	44.4
Blackhull selection	11737	—	—	12.0	59.1	35.6
Cheyenne	8885	0	66.7	0	23.1	22.5
Cheyenne selection	11666	2.5	100.0	15.4	—	39.3
Cheyenne × Tenmarq	11972	—	—	—	80.6	80.6
Cheyenne × Tenmarq	11973	—	—	—	42.9	42.9
Chiefkan	11754	—	—	—	35.5	35.5
Comanche	11673	54.4	—	42.1	85.7	60.7
Cooperatorka	8861	—	—	0	17.6	8.8
Early Blackhull	8856	—	0	—	66.7	33.4
Early Blackhull Hybrid	11846	—	—	54.5	65.0	59.8
Early Blackhull × Tenmarq	11952	—	—	47.6	100.0	73.8
Early Kanred	8261	0	0	0	50.0	12.5
Fort Collins selection	11971	—	—	0	0	0
Fulhard	8257	—	—	—	8.3	8.3
Hd. Fed. × Kawvale, Ks. J341734	—	9.4	0	15.4	13.3	9.5
Hope × Cheyenne	11969	—	—	—	0	0
Hope × Kawvale, Ks. J352882-4	—	—	—	—	0	0
Hope × Kawvale, Ks. J352883-4	—	—	—	—	0	0
Hope × Kawvale, Ks. J352886-2	—	—	—	4.8	0	2.4
Hope × Kawvale, Ks. J352897	—	—	—	—	0	0
Hope × Kawvale, Ks. J361619	—	—	—	—	0	0
Kanhull	11877	0	0	0	46.2	11.5
Kanred	5146	0	—	63.2	—	31.6
Kanred × Blackhull	11844	—	—	0	21.4	10.7
Kanred × Hard Federation	10092	2.7	—	—	—	2.7
Kanred-Hd. Fed. × Minh.-Mint.	11970	—	—	71.4	75.0	73.2
Kanred × Hope	11976	—	—	—	0	0
Kanred × Hope-Hard Federation	11975	—	—	0	33.3	16.7
Kanred × Marquis	11589	23.6	40.0	31.2	44.4	34.8
Kanred × Marquis	11746	0	—	0	28.6	9.5
Kanred × Kanred-Marquis	11592	0	—	—	—	0
Kan.-Web.-Kan. × Hd. Fed.-Marq.-Marq	11977	—	—	—	75.0	75.0
Kawvale × Marquillo, Ks. 2848-4	—	—	—	—	4.3	4.3
Kawvale × Tenmarq	11750	0	10.0	7.5	0	4.4
Kawvale × Tenmarq	11950	10.4	0	50.0	37.5	24.5
Kawvale × Tenmarq	11951	—	—	16.7	0	8.4
Kawvale × Tenmarq	11953	—	—	47.8	45.5	46.7
Kawvale × Tenmarq	11956	—	—	0	23.5	11.8
Kharkof	1442	5.2	—	4.8	56.2	22.1
Marquillo × Oro, Ks. FN 787-1	—	—	—	—	35.3	35.3
Minh.-Mint., C.I. 8034, × Tenmarq	11668	11.2	—	—	—	11.2
Minturki	6155	0	—	38.9	52.6	30.5
Minturki × Blackhull	11671	12.0	—	0	31.2	14.4
Minturki × Blackhull	11815	—	—	0	33.3	16.7
Nebraska No. 60	6250	44.6	30.0	80.0	55.0	52.4
Nebred	10094	0	25.0	72.2	—	32.4
Oro	8220	0	—	33.3	66.7	33.3

TABLE 2.—*Continued.*

Variety or strain	C.I. No.	Loose smut infection, %				
		1938	1939	1940	1941	Av.
Oro × Fulhard	11579	0	40.0	4.8	45.0	22.5
Oro × Tenmarq	11672	38.0	—	45.0	81.3	54.8
Pawnee	11669	0	0	0	0	0
Penquite selection	11745	8.6	42.9	0	30.4	20.5
Prelude × Kanred	11591	56.4	—	—	—	56.4
Quivira	8886	47.4	—	54.5	91.7	64.5
Ridit	6703	0	—	50.0	52.4	34.1
Sibley No. 62	11523	0	—	58.8	—	29.4
Sibley No. 62 × Hd. Fed., Ks. J361774	—	—	—	0	5.0	2.5
Sibley No. 62 × Hd. Fed., Ks. J361771-4	—	—	—	10.0	37.5	23.8
Sinvalocho	12096	—	—	—	0	0
Tenmarq	6936	9.2	—	40.0	78.9	42.7
Tenmarq × Minturki	11580	46.2	100.0	77.3	—	74.5
Tenmarq × Nebraska No. 28	11847	—	—	66.7	53.8	60.3
Turkey selection	10016	8.7	—	39.1	—	23.9
Turkey selection	10083	4.4	85.7	85.7	—	58.6
Turkey selection	11530	—	—	—	42.9	42.9
Turkey selection	11576	5.0	—	0	12.5	5.8
Turkey selection	11577	0	10.0	68.8	—	26.3
Turkey selection	11667	3.3	—	7.1	33.3	14.6
Turkey selection	11734	—	—	—	50.0	50.0
Soft Red Winter Wheat Varieties and Strains						
Berkeley Rock	8272	0	0	0	0	0
Clarkan	8858	0	12.5	92.6	80.0	46.3
Denton	8265	15.9	44.0	44.4	84.2	47.1
Diehl-Mediterranean	1395	—	—	—	89.5	89.5
Early Premium	11858	0	0	0	0	0
Flint	6307	—	—	—	0	0
Forward	6691	0	0	0	0	0
Fulcaster	6471	35.0	6.3	25.0	42.1	27.1
Fultz	3416	71.8	100.0	89.3	96.3	89.4
Gasta	11398	—	—	—	0	0
Gipsy	3436	—	—	—	0	0
Goens	4857	—	—	—	76.7	76.7
Harvest Queen	6199	0	—	0	21.4	7.1
Hope × Mediterranean, 41-16-3-3	—	—	—	—	0	0
Hope × Mediterranean, 41-33-1-J13-1	—	—	—	0	0	0
Hope × Mediterranean, 41-33-1-J19-3	—	—	—	0	0	0
Hope × Mediterranean, 41-230	—	—	0	0	0	0
Hope × Mediterranean, 41-C1730	—	0	0	0	0	0
Hope × Mediterranean, 41-C1799	—	0	0	0	0	0
Hope × Mediterranean, 41-C2012	—	0	0	0	0	0
Hope × Mediterranean, 41-C2280	—	0	0	0	0	0
Hope × Mediterranean, 41-C2766	—	0	0	0	0	0
Illini Chief	5406	—	—	—	62.5	62.5
Imperial Amber	5338	—	—	—	66.7	66.7
Jones Fife	4466	0	0	14.2	9.1	5.9
Kawvale	8180	0	0	0	0	0
Leap	4823	0	0	0	0	0
Lofthouse	3275	—	—	—	27.8	27.8
Mediterranean sel. 3015-81	10086	6.7	—	80.0	—	43.4
Mediterranean sel. 3015-105-1	11587	2.0	38.5	63.2	—	34.6

TABLE 2.—*Concluded.*

Variety or strain	C.I. No.	Loose smut infection, %				
		1938	1939	1940	1941	Av.
Mediterranean sel. 5933-20	10085	38.1	46.2	93.8	—	59.4
Mediterranean sel. 5933-23	11525	20.2	—	57.9	—	39.0
Mediterranean sel. 5933-38	—	21.2	100.0	67.6	—	62.9
Minhardi	5149	0	0	0	0	0
Nabob	8869	—	—	—	0	0
Nigger	5366	—	—	—	0	0
Nittany	6962	—	—	—	0	0
Nured (Cornell 250a-1-5-7)	—	0	0	0	0	0
Oakley	6301	—	—	—	0	0
Poole	3488	—	—	—	0	0
Portage	5654	—	—	—	0	0
Purdue No. 4	11932	0	0	0	0	0
Purplestraw	1915	0	0	0	0	0
Red Chief	3392	—	—	0	—	0
Red Clawson	3393	—	—	—	7.7	7.7
Redhart	8898	—	—	—	27.3	27.3
Red May sel., Tex. 7250-1	—	32.9	100.0	91.7	100.0	81.2
Red Rock × Hope, Ks. J361588	—	—	—	0	27.3	13.6
Rice	5734	—	—	—	0	0
Ruddy	6465	—	—	—	0	0
Rupert	5920	—	—	0	31.8	15.9
Russian	5737	—	—	72.2	50.0	61.1
Russian Red	5928	—	—	—	25.0	25.0
Shepherd	6163	0	—	82.1	50.0	44.0
Thorne	11856	—	—	—	0	0
Trumbull	5657	—	—	—	0	0
Valprize	11539	—	—	0	0	0
V. P. I. 131	10047	—	—	—	50.0	50.0
Walker	6445	—	—	—	5.0	5.0
Zimmerman	2907	0	0	0	0	0
White Winter Wheat Varieties						
Arco	8246	0	50.0	30.0	0	20.0
Dawson	3342	0	—	0	—	0
Genesee Giant	1744	—	—	0	—	0
Greeson	6320	—	—	—	0	0
Honor	6161	0	0	15.8	36.4	13.0
Honor-Forward, Cornell 501e-1-28	—	0	0	0	38.4	9.6
Martin's Amber	4636	—	—	—	8.3	8.3
Club Wheat Varieties						
Coppei	4238	—	—	8.3	53.8	31.0
Hybrid 128	4512	—	—	14.3	72.7	43.5

ferring to other hard red winter wheats. Several Hope × Kawvale selections, developed by Mr. C. O. Johnston, Bureau of Plant Industry, U. S. Dept. of Agriculture, at the Kansas Experiment Station, were resistant to date. These strains are also highly resistant to leaf and stem rusts. Other selections resistant in these tests are Kanred × Hope (C.I. 11976)[4] and Hope × Cheyenne (C.I. 11969).

[4]C.I. refers to accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

Soft winter wheat varieties tested for 4 years and so far resistant include Kawvale, Leap, Berkeley Rock, Early Premium, Purdue No. 4, Purplestraw, Minhardi, Zimmerman, Forward, and Nured. Of these strains, Kawvale appears to be one of the most desirable since it has been reported as resistant by Caldwell (2), Wingard and Fromme (10), Taylor and Bayles,[5] and in Russia by Artemoff (1), in addition to the present tests. Forward and Purdue No. 4 have been resistant to loose smut at Denton but were reported by Caldwell (3) to be susceptible to some collections in Indiana. The resistance of Forward also has been reported by Tapke (8) and Wingard and Fromme (10). Leap wheat, resistant in the present tests, was reported resistant to loose smut as early as 1926 by Fromme (4) and by Tapke (8), but in recent tests by Taylor and Bayles strains of Leap have shown susceptibility to some collections. Other selections which have been made were resistant to the inoculums used. Early Premium, Zimmerman, and Purplestraw are reported to be susceptible when grown in parts of the eastern United States but were resistant in the present studies. Trumbull, which has been tested only 1 year at Denton, Tex., was reported highly resistant by Caldwell (3). Harvest Queen, Fulcaster, and Russian (C.I. 5737) were resistant in tests by Tapke in 1929 (8), but were fully susceptible in the present tests. A number of other strains were resistant for 1 or 2 years but further testing will be necessary to establish the true reaction of these strains. Honor and Honor-Forward (Cornell 501e-1-28) were resistant in 1938 and 1939 but in 1940 and 1941 were susceptible, which may indicate the presence of different physiologic races in the latter seasons.

A large number of strains from the Hope × Mediterranean cross, developed for Texas conditions, have been tested for reaction to loose smut. Of these, 23 have been completely resistant to date, while 10 have shown an average infection of less than 10%. Most of these strains are also highly resistant to leaf and stem rusts. A few of the better strains are given in Table 2, including selection 41-16-3-3 which has been increased for distribution in central Texas. These strains constitute valuable parental material for Texas conditions and are being used in further breeding work.

SUMMARY

Artificial inoculation of a large number of winter wheat varieties by means of Moore's vacuum spore-suspension method was carried out under field conditions at Denton, Tex., during the period from 1938 to 1941, inclusive. Preliminary tests of methods showed that heads should be inoculated at the early to midanthesis stage of growth and that inoculations could be made at any time of day regardless of the humidity of the outside air.

None of the commercial hard red winter wheat varieties tested were resistant. Pawnee, a new variety now ready for distribution by the Nebraska Agricultural Experiment Station, was completely resistant like its Kawvale parent. Several Hope hybrid selections were resistant to loose smut, as well as to leaf and stem rusts.

[5]Private conversation.

Kawvale, Forward, Purdue No. 4, Leap, Zimmerman, Purplestraw, Early Premium, and Minhardi were resistant to smut throughout the period. A number of other varieties were resistant for shorter periods and further testing is necessary to establish their reaction. A large number of Hope × Mediterranean selections developed in Texas combine resistance to loose smut, leaf rust, and stem rust. It is suggested that these strains and Kawvale provide the best adapted and most resistant parental material for use in the breeding program in Texas.

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THE EFFECT OF CERTAIN PASTURE PRACTICES ON RUNOFF AND PRODUCTION OF PROTECTIVE COVER[1]

J. L. HAYNES AND O. R. NEAL[2]

IN 1937 a study was initiated to supply information concerning effects of pasture management practices on runoff, erosion, and yield that would be applicable to the northeastern dairy region. This paper reports a 4-year summary of the results obtained.

As originally designed, variables of pasture practices considered were rotational grazing and fertilizer compared with continuous grazing without fertilizer. During the last year of study, the design was modified to include a comparison of rotational grazing without fertilizer and continuous grazing and fertilizer.

The study was carried out on Dutchess stony loam at Sussex, N. J., on land furnished by the New Jersey Dairy Research Station. The Dutchess and associated soil series are representative of approximately 3½ million acres in the northeast, lying principally in the Hudson Valley. The topography of much of the area is strongly rolling and the erosion hazard may be considerable under some systems of land use.

EXPERIMENTAL HISTORY AND METHODS

The experimental site was plowed from sod in the fall of 1936 and in the spring of 1937 was seeded to a mixture of white, red, and alsike clover, Kentucky bluegrass, redtop, and timothy. A light hay crop was removed in 1937, but grazing was withheld until the following spring. The experimental area had a 20% slope.

Six 7/10 acre plots were fenced to be used as grazing units. Within each grazing unit, a 14 by 70 foot plot was enclosed with steel border plates and equipped for the measurement of soil and water losses.

Field designations of the respective pasture practices considered are as follows:

Field series	Pasture practice and treatment
A	Rotational grazing and fertilizer
B	Continuous grazing without fertilizer
C	Continuous grazing with fertilizer
D	Rotational grazing without fertilizer

Series A and B were each represented by triplicate plots in 1938, 1939, and 1940, and by duplicate plots in 1941. Series C and D were represented in 1941 by single plots that were obtained by reversing previous grazing practices on one plot each from series A and B.

At the beginning of the study, the pH of the soil was 5.8. During the course of the investigation, series A and C were limed as needed to maintain a pH of 6.5. The fertilizer treatment on these series is given in Table 1. Series B and D were

[1]Contribution from the Soil Conservation Service, Office of Research, U. S. Dept. of Agriculture, and of the New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, N. J. Received for publication November 10, 1942.

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neither limed nor fertilized. Tests for available phosphate and potash were made by Purdue quick-test methods (3)[3] on soil samples taken at the beginning and at the end of the study. Results obtained are shown in Table 2.

TABLE 1.—*Treatment history of fertilized pasture plots.*

Year	N, lbs. per acre*	P_2O_5, lbs. per acre	K_2O, lbs. per acre	Lime, tons per acre
1938	48	120	50	1.5
1939	48	0	0	1.5
1940	49	50	50	0
1941	54	60	125	0

*Nitrogen was split into April and June applications.

TABLE 2.—*Summary of nutrient tests of composite soil samples from the 0–8 inch layer.*

Year	Field series	Relative amounts of available nutrients		pH
		Phosphate	Potash	
1937	A, B, C, D	42	173	5.8
1941	A, C	77	100	6.6
1941	B, D	37	40	5.7

The grazing load on the continuously grazed series was maintained at carrying capacity, but severe overgrazing was avoided. Management of the continuously grazed series of this study is thus more or less comparable to the conditions of the controlled grazing in some earlier reported results (4) concerning the influence of pasture management on soil and water conservation.

The rotationally grazed series were allowed to reach a height of approximately 4 inches before each grazing period, at which time a sufficiently heavy load was applied to graze the plots to ½ to 1 inch height in approximately 10 days.

Clipping of weeds and spreading of droppings was practiced on all series. Salt and water were placed at opposite ends of each plot to further encourage uniform grazing. The plots for soil and water loss measurements were so located within each grazing unit that grazing on the plot was entirely comparable with that on the remainder of each unit. Holstein and Guernsey heifers 14 to 24 months old were used for grazing.

Soil and water losses under the different systems of management were measured separately following each storm that caused runoff.

Animal gains were determined from means of three successive weighings from dry lot made at the beginning and again at the end of each grazing season. Gains for each animal were pro-rated to each plot in proportion to the number of days grazed. Weights were calculated into 1,000-pound cow days per acre. Total digestible nutrients were computed from individual cow gains according to Morrison standards (1). Grazing cages 3 by 3 feet were placed in each grazing unit and clipped at the end of grazing periods on the rotational plots. Location of cages was changed after each clipping. For purposes of estimating grazing aftermath, quadrats near the cages were harvested at the time of cage clipping. No aftermath quadrat clippings were made in 1938.

[3]Figures in parenthesis refer to "Literature Cited", p. 211.

Changes in species composition were determined from plant counts made by the point quadrat method (2).

The analysis of variance method was used to test the significance of the treatment or pasture-practice differences observed. The data for all plots for the first 3 years and for the four plots not changed in 1941 were combined to test the significance of the difference between the practice of rotational grazing with applications of fertilizer and that of continuous grazing without fertilizer.

RESULTS

Runoff, erosion, and rainfall for the summer and winter seasons are shown in Table 3. Each listing is the mean of three plots. These data are summarized on the basis of pasture practice without regard to fertilizer applications. For the years 1938, 1939, and 1940, the rotationally grazed plots were all fertilized and none of the continuously grazed plots received fertilizer. During 1941, two of the rotationally grazed areas were fertilized and one was not, while one of the continuously grazed areas was fertilized and the remaining two were unfertilized.

Due to uneven drifting of snow across the experimental site during March, the runoff during that month bore little relation to the experimental variables or to the amount of measured precipitation. Records for the month of March are accordingly omitted from the records of the winter period. The differences indicated as necessary for significance in Table 3 are based upon analysis of data for all years listed.

TABLE 3.—*Runoff and erosion from pasture under rotational and continuous grazing.*

Year	Runoff in surface inches		Soil loss in pounds per acre		Rain-fall, inches
	Rota-tational grazing	Con-tinuous grazing	Rota-tational grazing	Con-tinuous grazing	
Six Months, April to September, Inclusive					
1938	2.08	3.27	251	281	37.75
1939	0.03	0.12	11	28	17.61
1940	0.08	0.24	6	55	26.94
1941	0.04	0.10	7	13	20.51
Differences necessary for significance	1.05		93		
Five Months, October to February, Inclusive					
1938–39	2.66	4.58	203	286	18.29
1939–40	1.08	1.28	3	17	11.77
1940–41	2.03	1.95	4	11	14.06
Differences necessary for significance	1.06		192		

Statistically significant differences in soil loss between the two management systems were not found at any time during the course of the study. This is true for both the growing season and the winter season. Following the year of establishment of the plots, the soil losses were extremely small under either system of management.

Differences in water loss were significant only during 1938. The precipitation for that year was considerably higher than for any ensuing year of the study. Following 1938, water losses were very small under either treatment during the growing season. Winter season losses were somewhat larger but showed no significant effect of treatment.

These results emphasize the fact that grass and legume cover, with a reasonable avoidance of overgrazing, provides an effective measure of control of erosion and water losses. Following the year of establishment of the seeding, losses of soil and water were very small on these areas having a 20% slope.

Mean annual yields from different pasture management systems, as expressed by grazing load and animal gains, are shown in Table 4, together with length of grazing season and precipitation during the pasture season. The total number of days during the grazing season (Table 4) represents the interval during which all of the available forage was utilized on the continuously grazed series. On rotationally grazed series, the animals were not on the areas for the entire period shown due to the practice of allowing the grass to reach a given height between grazing periods.

TABLE 4.—*Comparison of means of yearly animal yields from different pasture practices and treatments.*

Year	No. of plots	1,000-lb. cow days per acre	Total digestible nutrients, lbs. per acre	Total animal gain, lbs. per acre	No. of days between 1st and last grazing	Rainfall from May to August, total inches
Series A, Rotationally Grazed and Fertilized						
1938	3	253	3,910	501	151	25.10
1939	3	153	2,110	256	115	10.44
1940	3	214	2,710	315	139	18.70
1941	2	262	3,670	451	127	18.19
Series B, Continuously Grazed Without Fertilizer						
1938	3	249	3,760	455	193	+8.66*
1939	3	207	2,780	307	168	−6.00*
1940	3	175	2,190	242	153	+2.26*
1941	2	151	2,110	250	136	+1.75*
Series C, Continuously Grazed with Fertilizer						
1941	1	306	3,820	411	146	——
Series D, Rotationally Grazed Without Fertilizer						
1941	1	144	1,930	229	89	——

*Inches deviation from average.

The analysis indicated a highly significant difference between pasture practices, i.e., rotational grazing with fertilizer vs. continuous grazing without fertilizer, between years, and a highly significant interaction between years and pasture practice. The high significance was reflected in each of the yield components of cow days, total digestible nutrients, and animal gains.

As pointed out earlier, series C and D were obtained for the 1941 year by reversing the grazing practice on one plot each from series A and B. This procedure provided one area that was rotationally grazed without fertilizer additions and one area continuously grazed with fertilizer treatment. During the first year following this change, it seems probable that the results were influenced by the treatments and management on these areas during the previous three years. This is substantiated by the fact that the yield from series C which had previously been fertilized and rotationally grazed was much higher than that from series D where the previous treatment had been continuous grazing without fertilizer applications. The short length of the grazing season for series D reflects the relatively longer period of the time required for the vegetation on that area to reach the height specified for the initiation of grazing.

The differences in yield between series A and series B, as shown in Table 4, were significant in 1939 and 1941, but the order of these differences is reversed. An indication of the reason for the smaller yield from Series A may be obtained from the data in Table 5. As indicated by the grazing-cage yields, a substantially larger amount of forage was produced on series A than on series B in 1939. Since this was the case, the reduced animal yield on series A appears to have been a function of grazing management. The design of the grazing system was such that grazing periods under the rotational plan were delayed until the grass reached a height of four inches. During drought years a considerably longer period of time was required for

TABLE 5.—*Average annual forage yield from grazing cages under different pasture practices.*

Management	Treatment	Year	Oven-dry forage, tons per acre		Utilization as indicated by clippings, %
			Grazing cage	Aftermath quadrat	
Rotationally grazed	Fertilized	1938	5.04	None taken	—
		1939	4.46	1.21	73
		1940	4.26	1.43	66
		1941	4.51	1.43	68
Rotationally grazed	Unfertilized	1941	3.30	1.13	66
Continuously grazed	Unfertilized	1938	5.10	None taken	—
		1939	2.79	0.59	79
		1940	3.41	1.03	70
		1941	2.36	0.70	70
Continuously grazed	Fertilized	1941	3.99	1.18	70

the grass to reach this height, and, as a result, relatively fewer periods of grazing were obtained during these years.

The results in Table 5 permit a comparison of oven-dry yields from grazing cages and aftermath quadrats. Results from grazing cages are not normally an accurate quantitative evaluation of the forage actually consumed by grazing animals. However, a comparison of the yields in Table 5 gives an indication of the relative utilization obtained under the respective management systems.

A lower percentage of forage utilization occurred under rotational grazing during the three years these records were collected. This condition is influenced by the fact that grass consumed under continuous grazing is relatively succulent, while a tendency toward lignification and associated unpalatability occurs under rotational grazing. The relative unpalatability of forage under rotational grazing would be influenced by the length of interval between grazing periods. This, in turn, would be controlled largely by the amount and seasonal distribution of rainfall, and possibly by the interaction of rainfall and fertility practice.

Annual changes in grass-legume ratio and grass and legume population of series A and B are listed in Table 6.

TABLE 6.—*Average percentage of ground cover during September for the 4 years of pasture study.*

Species	Fertilized, rotationally grazed				Unfertilized, continuously grazed			
	1938	1939	1940	1941	1938	1939	1940	1941
Seeded grasses	44.5	78.3	90.0	80.1	49.6	60.3	71.7	74.1
Volunteer grasses	—	3.0	7.6	1.3	—	1.0	16.6	0.9
Total grasses	44.5	81.3	97.6	81.4	49.6	61.3	88.3	75.0
Seeded legumes	39.0	10.5	—	10.4	35.0	13.6	3.2	9.0
Volunteer legumes	—	—	0.4	—	—	—	—	1.6
Total legumes	39.0	10.5	0.4	10.4	35.0	13.6	3.2	10.6
Total weeds	13.2	5.0	1.3	8.2	12.7	11.1	4.8	13.9
Bare ground	3.3	3.3	0.7	—	3.3	14.0	3.7	0.5

It will be noted from the data in the above tabulation that most of the legume population was lost during the dry year of 1939. Recovery during subsequent years was slow with no significant difference in the rate of recovery shown as a result of the two management practices considered.

SUMMARY

1. During the first year of the investigation, when rainfall was unusually heavy, runoff from continuously grazed pasture was significantly higher than from rotationally grazed areas. During the ensuing 3 years, good control of runoff was afforded under both systems with no significant differences as a result of management practices.

2. Erosion losses under the two systems of grazing were not significantly different. Excellent control of soil losses was afforded by each of the management systems.

3. Rotational grazing with fertilizer applications showed a significantly higher yield than did continuous grazing without fertilizer.

4. During a drought year, the animal yield was larger under unfertilized continuous grazing than under fertilized rotational grazing.

5. The percentage of available forage utilized by grazing animals was less under rotational grazing than under continuous grazing.

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EFFICIENCIES OF THE LESPEDEZA-SMALL GRAIN ANNUAL ROTATION IN MISSOURI[1]

W. C. ETHERIDGE[2]

IN the radical adjustment of American agriculture during the last decade, the phenomenon of change has become commonplace. We only glimpse an unusual development before it quickly moves out of focus, to be sharply and briefly replaced by another in the rapid farm panorama. So it is that the almost sudden shift in Missouri from the long and faltering rotations of corn with other grains and sometimes a successful legume to a new system of short precise rotations of grains with regularly successful leguminous pastures and forages may have received only passing attention by national observers.

But neither the quick look nor the casual judgment from abroad can lessen at home the native appreciation of the deep and permanent effect of this change in Missouri; for it is change scarcely short of revolution, so far as benefits to crop farming and correlated livestock farming are concerned. The whole transformation derives principally from a new legume, Korean lespedeza (*L. stipulacea*), and the efficiency of its main implementation, the short turn of lespedeza with any of the smaller cereals—wheat, oats, barley, rye—annually and continuously on the same field.

The great popularity of lespedeza and of the short rotation which usually contains it is readily shown. After an experimental period of 8 years at the Missouri Experiment Station and a short demonstration period which first brought conspicuous results in 1930, Korean lespedeza has expanded so rapidly that in 1941 we find it being grown on 95% of all Missouri farms for a total of 7,396,700 acres, with an estimated million acres of non-farm land added for good measure. Incidentally, the Missouri acres of all farm legumes passed the 10 million mark in 1941 and amounted to 52% of all land actually in crops and 35% of the total area classified as crop land—a leguminous proportion unprecedented anywhere. Of all farms then growing lespedeza 105,066, or 42%, were regularly using the annual rotation of lespedeza with small grain, and most of the remainder were using it frequently. This seems a record in mass adoption of a new crop and of a new technic in crop production.

The continuous annual rotation, on the same field if desired, of lespedeza and small grain is not only the best and principal method of growing lespedeza; it is also the dynamic agent of the whole Missouri system of pasture farming. First let us see how it works, using lespedeza-wheat as an example, although procedure and returns are essentially similar if a different grain is grown in place of wheat.

The rotation is established by sowing lespedeza on wheat in winter or early spring. From soon after the wheat is harvested in June, the

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lespedeza may be grazed until the end of the season in October, or it may be saved for midsummer hay or a fall crop of seed, or by correct management harvested successfully for both purposes. In the fall when the lespedeza seed is ripe or nearly ripe, the sod is disked and harrowed, or similarly cultivated, and wheat is sown on it. There will be plenty of seed left on the lespedeza ground for a thick volunteer stand in the wheat next spring. The rotation may be continued as long as it is wanted, wheat being sown on the lespedeza sod every fall, always with such mineral fertilizer as seems desirable. A variation would be to graze out the wheat in the spring, in which case wheat-lespedeza would furnish about 6 months of highly productive pasture.

A grain crop and a legume crop well grown on the same land in the same year add up to a large annual return per acre. Thus on a field at the Missouri Station in the normal seasons of 1938, 1939, and 1940, the average acre yields of 24 bushels of wheat and 133 pounds of live-weight gain by beef cattle which grazed lespedeza after the wheat must be considered very high production, especially on land having a normal average capacity of only 25 to 30 bushels of corn. Direct alignment with yields of wheat under other conditions for the same period is not available except by straining a statistical conclusion; but in small agronomic plots nearby, where each step conducive to maximum production from seeding to threshing was taken with the most scrupulous care, the yield of wheat following oats in a long standard rotation reached an average of 30 bushels. Every experienced agronomist knows that a 6-bushel difference between plot scale production with its multiplied artful perfection and field scale production with its numerous inequalities may not imply an unfavorable performance of the field; and many thousands of Missouri farmers, whose judgment is sensitive to variations in profit, know by experience that lespedeza sod is a favorable place for a good wheat crop.

A definite economy in the acre cost of producing wheat is gained in the wheat-lespedeza rotation by substituting disking or other light manipulation for expensive plowing in preparing the lespedeza sod for sowing the wheat. And this is clear gain, for such superficial treatment would be required secondarily even if the land had previously been plowed. Additional reduction in cost is made, this time on the bushel basis, where productivity of the land is increased, as it readily may be, by the continued operation of this rotation.

Finally, if the estimate of cost is extended to include a whole grain-lespedeza unit, the importance of the total reduction becomes apparent. Lespedeza requires no special soil treatment for itself, though it is definitely benefited by any good treatment, direct or indirect. Also, the first cost of seeding lespedeza is very small by comparison with the cost of seeding any other legume ordinarily associated with a small grain crop; and later there is no cost at all, as the lespedeza volunteers every spring. Therefore, the grain-lespedeza unit as compared with such other units as wheat-red clover or wheat-sweet clover is cheaply produced.

The continuous yearly production on the same land of the grain-lespedeza rotation reaches a high standard of soil treatment by fertilizing each grain crop with the needed minerals and grazing at least a part of each crop of lespedeza. Thus there would be a maintenance or perhaps a build-up of mineral content and certainly a substantial increase of nitrogen and organic matter—all clearly favorable to basic fertility. No quantitative measurement of soil improvement under grain-lespedeza has been made, but qualitative indications of a beneficial effect are common. The vigorous growth of bluegrass—an honest witness to the fact of fertile soil—soon becomes troublesome in the preparation of lespedeza sod for sowing the grain crop, even where no sign of bluegrass was seen when the rotation was started. Incidentally the continued stand of grain-lespedeza is the best means, counting economy, of starting or restoring bluegrass in Missouri, though indeed not the only good way in which the job may be done.

Experimental evidence on the efficiency of the grain-lespedeza partnership in controlling soil erosion is conclusive. At the Bethany Soil Erosion Station the annual soil loss from lespedeza land was only 1.6 tons per acre, and the water runoff was only 11.7% of the 32.5 inches of rainfall received. The 3-year average loss of soil under oats-lespedeza on contour was only 60% of the loss under corn-oats-meadow, even where the latter rotation was aided by the soil saving device of strip cropping. At the McCredie Soil Erosion Station the average loss of soil under various grain-lespedeza annual combinations amounted to only half the loss under a corn-oats-meadow rotation in a whole year of excessive rainfall. Mulch culture, a new concept in the control of soil erosion, is exemplified on a vast scale by the millions of acres of Missouri lespedeza sod—a mulchy stratum disked into the soil but not disked under in preparing for the sowing of grain and providing optimum conditions for the absorption of moisture and the prevention of runoff.

Grain-lespedeza is safer than grain alone or grain-red clover, when safety is measured by financial returns, for the following reasons: (1) The probability of a return is doubled, for if grain fails, lespedeza still gives its own quota. If wheat partly fails, the remainder may be utilized in a thrifty way by spring grazing, followed by summer grazing of the lespedeza. Grain-lespedeza pasture is an excellent method of feed production, whether grain itself partly fails or wholly succeeds. (2) Lespedeza is a far more reliable crop than red clover, for the production of red clover has become uncertain and difficult as a result of declining soil fertility, inferior seed, accumulated insects and diseases, and frequent droughts.

Wheat in particular is perhaps safer with lespedeza than where it is grown alone because (1) the comparatively late seeding of wheat on the lespedeza sod is an effective means of controlling Hessian fly; (2) chinch bug infestation is less in wheat containing a volunteer stand of lespedeza as the insect will tend to avoid the exceedingly dense shade produced by the spring growth of this legume; (3) grub worms, cut worms, and wire worms, all infesting a long-standing sod like clover and timothy and all causing some damage to wheat which

follows such a sod, are dispersed and repelled by the annual cultivation of the lespedeza sod in preparation for the wheat crop; (4) the losses from spring heaving are reduced as the lespedeza sod disked in the fall and sown to wheat does not heave as severely as ground that was plowed in the previous summer or fall; (5) the losses from erosion are reduced, as previously explained.

Grain-lespedeza can be managed with comparative ease and certainty for the following reasons: (1) The amount of labor required by the rotation is not large, since there is little or no plowing to be done for grain and the lespedeza is usually grazed. (2) The regularity of performance is unequalled by any other rotation that includes a legume. Lespedeza invariably volunteers thickly in the spring, thus assuring the grower of a legume every year, barring occasional small losses by drought. This is in striking contrast to the frequent failures of other legumes associated with grain in other rotations—failures which cause an immediate loss of money and throw out of step the plan of production.

In judging the comparative returns from the grain-lespedeza method, let us look at the whole annual unit. This puts the matter on a basis of the total yearly returns from an acre of land, which is a reasonable and sound consideration. The acre is highly productive which in a year yields a grain crop and a heavy legume pasture or hay crop, the pasture alone being fully equal in feed value to good bluegrass for a full season on similar land. Our livestock fed bountifully and economically from this well-balanced rotation have flourished and multiplied in recent years. In 1942 each class of Missouri farm animals, except horses and mules, has reached an all time peak in numbers and condition of productivity. There lies the final and incontestable proof of the efficiency of our pasture farming system, including the grain-lespedeza rotation as its most important single factor—a system which symbolizes the conservative and profitable use of Missouri farm land.

AGRONOMIC TESTS OF NEW RESISTANT VARIETIES AND HYBRIDS OF HARD RED WINTER WHEAT IN THE PRESENCE OF STEM RUST AND HESSIAN FLY[1]

L. P. Reitz, E. T. Jones, C. O. Johnston, and R. H. Painter[2]

STABLE and efficient farm production is based upon regular harvests of good crops. The present commercial varieties of hard red winter wheat produce well in favorable years but may be damaged severely in some seasons by plant diseases, insects, or unfavorable climatic conditions. Two important pests of winter wheat are the Hessian fly, *Phytophaga destructor* (Say), and stem rust, *Puccinia graminis tritici* (Eriks. and Henn.). It is the purpose of this paper to report protection afforded by inherent resistance to stem rust and Hessian fly in hard winter wheat varieties and hybrids developed during the past few years.

Recently, Melchers (3)[3] has called attention to the severity of stem rust losses in Kansas during the period 1935 to 1940 when four stem rust epiphytotics occurred. Some of these were estimated to have caused more than 10% loss to the wheat crop of Kansas. A field survey of wheat stubble made at harvest time in 1941 showed that in eastern and central Kansas infestation by Hessian fly averaged approximately 20% of the culms. Gossard and Houser (1) reported an experiment in 1906 in which infested straws yielded 32.5% less grain than straws free of infestation. The loss to the 1941 wheat crop in Kansas from this insect was estimated by entomologists at Kansas State College to be 13,000,000 bushels. Other diseases and insects, especially leaf rust and grasshoppers, may in some years cause damage as extensive as that just cited.

For several years workers in the hard red winter wheat region have been engaged in transferring inherent disease and insect resistance from various sources to commercially satisfactory winter wheat varieties. In the Kansas plant breeding program, marked progress has been made by using Marquillo spring wheat as a source of resistance to both Hessian fly and stem rust. Painter, *et al.* (4) have reported certain Marquillo winter wheat hybrids as possessing commercially valuable resistance to Hessian fly, jointworm, stem rust, leaf rust, bunt, and mildew, a combination not previously reported in any winter wheat. Since that report was published, addi-

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[3]Figures in parenthesis refer to "Literature Cited", p. 229.

tional agronomic data have been secured on these and many other strains under three environments, *viz.*, (a) in the absence of severe disease epiphytotics or insect infestation, (b) in the presence of a stem rust epiphytotic, and (c) in the presence of heavy infestation of Hessian fly.

Data presented in this paper include comparisons of strains resistant to stem rust and Hessian fly with susceptible standard varieties and hybrids with particular relation to yield and plumpness of grain.

EXPERIMENTAL CONDITIONS

During the crop years 1940 and 1941, favorable conditions prevailed for growth of winter wheat at Manhattan, Kan. Disease infection and insect infestation were generally light. Hence, results at this station permitted an evaluation of the strains in the absence of major hazards. Yield tests were conducted by using three replicated plots for each strain, each plot consisting of three rows 16 feet long. Only the center row was harvested for yield determinations.

Nurseries at outlying points where Hessian fly infestations normally occur were maintained in 1940 near Ramona, Kan., and in 1941 near Springfield, Mo., to determine the resistance of advanced hybrids to Hessian fly. The entries were so arranged that two strains of resistant Marquillo hybrids, each planted in a single row, alternated with a single row of winter wheat not involving Marquillo which was susceptible to the fly. The soil at Ramona was so dry that stands from early sown wheat were not secured in the fall of 1939 until too late for fly infestation. Spring infestation was light and irregular, plant infestation of known susceptible varieties ranging from 12 to 82%. Late emergence and delayed fall growth at Ramona caused somewhat late development and heading of the wheat. As a result of these and other conditions, stem rust developed rapidly in June, damaging susceptible strains in the nursery as well as susceptible varieties grown on nearby farms. The apparent difference in resistance to stem rust, shown by various strains, was estimated by taking infection readings and the effects were measured by harvesting 5 feet from each row of the 216 entries planted in duplicate 8-foot rows for grain yield and test weight per bushel. The yields are given in grams produced per row rather than bushels per acre, owing to the shortness of the rows. This length of row is too short for best results, but, as will be shown later, analyses indicate a high degree of significance in the data. Stem rust readings were made on June 24 when infection was approaching its maximum on the later varieties and hybrids, and breaking of straw was becoming evident in susceptible strains.

Relatively uniform and high infestations of Hessian fly have occurred for many years in experimental wheat plots maintained at Springfield, Mo. In the crop year, 1940–41, stem rust infection was very light and no insect pests other than Hessian fly occurred in these plots in sufficient numbers to influence yield materially. Since Hessian fly damage was the only evident significant variable affecting yields, relative yields of all varieties grown in the plots were determined by harvesting 5½ feet from each 8-foot row in an effort to measure relative effect of resistance of the varieties to Hessian fly.

Analysis of variance was used to analyze for significance. Standard error of an average of averages was calculated from the formula $\frac{1}{N}\sqrt{\sigma_a^2 + \sigma_b^2 + \ldots\ldots\sigma_n^2}$ where a, b, and n represent individual standard errors.

EXPERIMENTAL RESULTS

DATA FROM MANHATTAN

Table 1 contains the average of data secured at Manhattan, Kan., on 40 varieties and strains of wheat during the two crop years, 1940 and 1941, where diseases and insects were of minor importance. A number of standard commercially successful varieties are included as a basis for evaluating the new strains. Sixteen of the Marquillo hybrids reported by Painter, *et al.* (4) are included in this summary, together with other selections from the same crosses. Data on a few non-Marquillo hybrids are also reported. The data include date of first heading, height, lodging, rust infection, test weight, and yield in bushels per acre. Brief data on certain varieties grown at Ramona, Kan., and Springfield, Mo., are also entered.

It will be observed that 6 of the 13 highest average yields at Manhattan are Marquillo crosses, while Tenmarq was one parent of six of the other seven selections representing five different crosses. Commercially grown varieties include Chiefkan, Early Blackhull, Tenmarq, Kawvale, Clarkan, Cheyenne, Blackhull, Turkey, Oro, and Kanred. Statistical treatment of the data revealed that only the first two entries in Table 1 significantly out-yielded Tenmarq (C.I. 6936), while the last four strains average significantly less than Tenmarq in these comparisons. From these data it appears that several types, including a few Marquillo hybrids, are available, which, in the absence of severe diseases or insect attacks, or unusually adverse weather conditions, give good yields. What the tested strains will yield under certain other conditions is indicated by the results from Ramona and Springfield discussed elsewhere in this paper. Several years of testing will be needed to establish the final varietal rank in yield.

The highest average test weight per bushel was made by Early Blackhull and Early Blackhull × Tenmarq, extremely early maturing strains. Altogether 12 varieties or strains gave test weights of 59 pounds per bushel or more, and in general gave good yields also. The lowest weight (55.8 pounds per bushel) was recorded for Marquillo × Oro 383493.

Date of first heading is used to indicate earliness or lateness in maturity. The data presented are in line with similar data recorded for the same strains in other years. Dividing the varieties and strains into four groups the following classification of the entries in Table 1 is possible:

Very early: Early Blackhull and Early Blackhull × Tenmarq.

Early: Quivira × Tenmarq, Pawnee, Comanche, seven strains of Marquillo × Tenmarq, four strains of Marquillo × Oro, and one strain of Cheyenne × Tenmarq.

Medium early: Kanred × Quivira, Chiefkan, Tenmarq, Blackhull, Kawvale, Clarkan, two strains of Marquillo × Tenmarq, 10 strains of Marquillo × Oro, and one strain of Cheyenne × Tenmarq.

Late: Cheyenne, Turkey, Oro, Kanred.

The varieties mature in approximately the same general order shown for heading except the Marquillo hybrids, especially strains of Marquillo × Oro, which tend to have a long fruiting period, often maturing with the group classified as late.

Lodging is difficult to measure accurately and may be the result of many causes. Turkey and Kanred are known to lodge badly, while Cheyenne is recognized as having stiff straw. The data show a few varieties or strains that stood up better than Cheyenne, but none lodged so badly as Turkey and Kanred. The Marquillo hybrids varied from 9 to 39% lodging. More data are needed to establish definitely the ranking of all strains, but there are indications that progress is being made toward resistance to lodging. Both stem rust and Hessian fly may cause the straws to become weakened, resulting in lodging, but when due solely to these factors little confusion with ordinary lodging occurs.

Damage from rusts was almost negligible on all varieties in 1940 at Manhattan so that the averages shown in Table 1 reflect principally the intensity of infection in 1941. Only five selections showed more than 10% stem rust infection. Of these, Quivira × Tenmarq was so near maturity by the time infection occurred that little damage resulted, while the varieties Chiefkan, Clarkan, Cheyenne, and Turkey were damaged to some extent by stem rust. Studies conducted in 1941 showed that almost all of the stem rust present belonged to physiologic race 17 to which some of the varieties, notably Tenmarq and Kanred, are resistant. Before 1941, race 56, a virulent race on most varieties of hard winter wheat and several other races were known to occur in epiphytotic proportions in Kansas.

Average leaf rust infection was severe (30% or above) on Turkey, Oro, Blackhull, Cheyenne, Early Blackhull and Early Blackhull × Tenmarq. The extent of damage caused can only be estimated, but it seemed apparent in the field that Turkey, Oro, Blackhull, and Cheyenne were greatly handicapped by the severe leaf rust infection. The two early varieties seemed to escape at least some of the damage. Only Marquillo hybrids showed leaf rust infection below 5%. Undoubtedly such resistance aided the Marquillo hybrids in making a good showing, but many other factors are involved in the ability to produce high yields of plump grain.

RESULTS AT RAMONA

Stem rust was the greatest single factor influencing the yield and test weight of the varieties and strains grown in the nursery at Ramona in 1940. The 216 varieties and strains grown in duplicate 8-foot rows gave ample evidence of the protection afforded by even moderate inherent resistance to stem rust. Fig. 1 illustrates the differences in yield and kernel plumpness among several of the strains.

Three strains were represented six times each in the nursery. They were Kawvale, Tenmarq and Marquillo × Tenmarq 37FN1507 for which the average yields were 65.3, 63.7, and 95.2 grams, respectively. Analysis showed that a difference of about 9 grams was significant. The average test weights for the same three varieties were 50.3, 52.2, and 59.0 pounds per bushel, respectively, with 1

TABLE 1.—*Data on agronomic characters, rust infection, and Hessian fly infestation for winter wheat varieties and hybrids grown in nurseries at Manhattan and Ramona, Kan., and Springfield, Mo., in the crop years, 1940 and 1941.**

Variety or cross	C.I., Kansas or Sel. No.	Manhattan, 2-year av.									Ramona, 1940			Springfield, 1941	
		Date first heading	Height, inches	Lodging, %	Rust, %		Test weight, lbs.	Yield, bus. per acre†			% stem rust	Yield, grams	Test weight, lbs.	% plants infested by fly in fall	Yield, grams
					Leaf	Stem		1940	1941	2-year av.					
Kanred × Quivira	Ks. 2763	May 20	41	22	14	8	60.3	43.8	40.0	41.9	—	—	—	—	—
Pawnee	C.I. 11669	May 18	37	22	19	6	59.1	40.3	37.6	39.0	60	88.5	54.7	100	22.3
Early Blackhull × Tenmarq	C.I. 11952	May 15	37	35	37	2	61.0	41.0	35.7	38.4	60	120.0	61.1	100	23.5
Cheyenne × Tenmarq	C.I. 11972	May 21	38	30	21	9	58.8	37.0	36.7	36.9	60	108.5	55.0	94	12.8
Marquillo × Oro	C.I. 11978	May 21	38	18	Trace	Trace	57.6	36.3	37.4	36.9	—	—	—	10	98.1
Marquillo × Tenmarq	383397	May 18	37	9	5	10	58.9	36.1	37.5	36.8	20	107.0	58.0	4	76.2
Quivira × Tenmarq	373924	May 17	38	6	20	18	59.8	37.9	35.2	36.6	60	92.5	58.3	—	—
Marquillo × Tenmarq	C.I. 12113	May 17	37	13	7	8	58.2	36.0	36.6	36.3	—	—	—	10	71.8
Marquillo × Tenmarq	384071	May 17	37	10	5	4	58.7	34.0	37.5	35.8	20	131.5	59.8	34	47.8
Marquillo × Oro	C.I. 11979	May 21	37	20	Trace	Trace	57.8	37.5	33.8	35.7	—	—	—	6	91.3
Marquillo × Oro	383426	May 20	36	13	2	Trace	59.0	33.5	37.4	35.5	10	103.5	58.7	16	45.5
Cheyenne × Tenmarq	373674	May 19	36	41	18	4	57.6	37.6	33.2	35.4	60	112.0	56.9	—	—
Comanche	C.I. 11673	May 18	37	19	18	5	58.8	36.7	33.2	35.0	80	97.0	55.2	96	6.4
Chiefkan	C.I. 11754	May 20	40	40	18	13	60.0	41.1	28.7	34.9	80	90.0	57.2	100	11.5
Marquillo × Oro	383442	May 18	36	19	2	2	59.5	34.2	34.3	34.3	5	117.5	58.8	0	60.0
Marquillo × Tenmarq	Ks. 2764	May 19	40	28	8	9	60.0	33.3	35.0	34.2	—	—	—	6	71.0
Marquillo × Tenmarq	37FN1507	May 19	39	24	4	1	60.0	35.7	32.2	34.0	47	95.2	59.0	5	65.7
Marquillo × Tenmarq	383344	May 18	38	25	4	6	58.0	33.2	34.5	33.9	40	106.0	58.6	20	53.8
Early Blackhull	C.I. 8856	May 13	38	39	33	1	61.2	31.8	35.8	33.6	40	99.5	61.4	96	15.3
Tenmarq	C.I. 6936	May 21	40	22	20	6	58.4	34.8	32.0	33.4	80	63.7	52.2	98	12.6
Marquillo × Oro	383481	May 20	37	28	2	Trace	57.6	32.3	34.0	33.2	—	—	—	16	71.5

Kawvale..............	C.I. 8180	May 22	41	7	12	8	56.7	33.5	32.7	33.1	82	65.3	50.3	91	19.5
Marquillo × Tenmarq	382879	May 19	37	28	4	7	58.2	28.8	34.7	31.8	—	—	—	8	51.3
Marquillo × Oro......	394448	May 19	37	32	3	2	58.0	33.7	28.9	31.3	—	—	—	12	65.8
Marquillo × Oro......	382984	May 20	36	29	2	Trace	56.2	31.2	30.4	30.8	20	86.0	57.2	0	58.0
Marquillo × Oro......	383493	May 20	37	14	2	Trace	55.8	32.8	28.7	30.8	—	—	—	2	76.0
Marquillo × Oro......	385628	May 19	36	30	3	Trace	56.2	30.2	31.1	30.7	5	108.5	56.9	0	97.5
Clarkan‡..............	C.I. 8858	May 22	44	17	23	30	59.5	37.8	23.2	30.5	85	43.0	49.4	100	7.3
Cheyenne............	C.I. 8885	May 23	38	15	40	17	58.8	35.2	25.6	30.4	60	54.5	51.6	98	7.9
Marquillo ×Oro.....	Ks. 2753	May 20	36	20	2	Trace	57.8	30.2	30.3	30.3	—	—	—	10	94.3
Marquillo × Oro......	383463	May 18	37	24	2	Trace	57.4	31.6	28.6	30.1	—	—	—	10	82.8
Marquillo × Tenmarq	382876	May 21	38	39	4	4	56.9	30.1	28.1	29.1	—	—	—	4	47.0
Marquillo × Oro......	C.I. 11980	May 21	36	15	2	Trace	57.4	29.8	28.3	29.1	—	—	—	2	90.5
Marquillo × Tenmarq	382888	May 20	38	23	5	9	57.9	33.4	24.5	29.0	—	—	—	4	57.8
Marquillo × Oro......	C.I. 11955	May 20	38	20	2	Trace	58.1	32.0	25.9	29.0	5	70.5	59.1	4	87.3
Blackhull............	C.I. 6251	May 21	41	50	41	8	59.1	34.9	21.3	28.1	80	82.5	56.6	100	7.0
Marquillo × Oro......	C.I. 11851	May 21	37	22	Trace	Trace	57.7	26.3	28.8	27.6	5	80.0	57.6	0	78.8
Turkey..............	C.I. 1558	May 23	40	68	31	23	56.3	32.8	21.5	27.2	—	—	—	—	—
Oro.................	C.I. 8220	May 23	39	14	30	4	57.3	33.1	20.6	26.9	80	61.0	48.5	96	1.6
Kanred..............	C.I. 5146	May 23	40	48	28	Trace	56.8	30.3	22.4	26.4	80	73.0	53.0	88	7.4

*Grown in rod rows at Manhattan and in 8-foot rows at Ramona and Springfield.
†Standard error of a difference between means for 1940 was 4.96 bus., for 1941, 3.00 bus., and for the two years combined, 2.70 bus. at Manhattan.
‡Grown both years in replicated 8-foot row series.

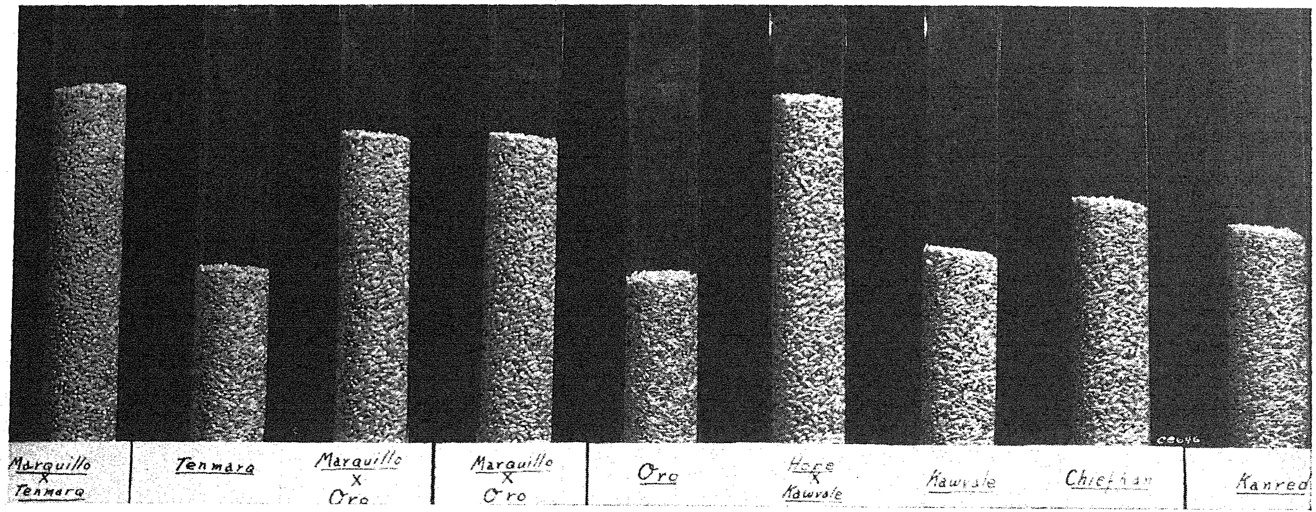

FIG. 1.—Grain from winter wheat varieties and hybrids grown at Ramona, Kan., in 1940, showing the relative yield and kernel plumpness of each entry. Stem rust was the major factor differentiating high and low strains. Infection ranged from a trace on Hope × Kawvale and Marquillo × Oro to 80% on Tenmarq, Oro, Kawvale, and Chiefkan.

pound needed for a significant difference. The average stem rust infections for these strains were 82, 80, and 47%, respectively, thus indicating the relatively lighter disease load carried by the one strain as compared to the others. By comparing these results with those from Manhattan as shown in Table 1, it is apparent that stem rust was an important contributor to the different performances shown by these three strains. The same appears true of others at Ramona also. Observation throughout the series showed that a significant negative correlation existed between the stem rust infection and both yield and test weight. Values for r calculated on one block of 88 entries were found to be as follows:

Stem rust and yield, $r = -0.5372$**
Stem rust and test weight, $r = -0.6044$**

Examination of the data shows that several varieties gave excellent yields and test weight despite high stem rust infection. Two such examples were Early Blackhull × Tenmarq (C.I. 11952) and Quivira × Tenmarq (Kans. sel. 373924). Each showed 60% rust infection but gave average yields of 120.0 and 92.5 grams and average test weights of 61.1 and 58.3 pounds, respectively. These two varieties were also outstanding in the Manhattan tests. It is probable that the earliness of these strains and resulting partial escape from rust account in a measure for their good performance even with a high rust infection. This is almost certainly true of Early Blackhull. A summary of the 216 strains studied at Ramona is given in Table 2 where comparisons of hybrids by stem rust infection classes can be made.

Three principal sources of stem-rust resistance, and perhaps others, are involved in the varieties and crosses represented in the series grown at Ramona. These sources are Kanred and similar types, Marquillo, and Hope. The Hope and Marquillo hybrids were the only ones to give infection readings below 20%, although not all selections involving one or the other of these as parents showed such excellence. The strains included at Ramona have been grown from 1 to 5 years in the rust nursery at Manhattan where epiphytotics are created artificially. Relative infection and injury were similar in the two nurseries.

Some Hessian fly in addition to stem rust infection was present in the spring at Ramona as indicated above. Correlation of spring infestation and yield for 88 strains gave a significant but low value for r of -0.2883. It seems, therefore, that stem rust, not Hessian fly, was the principal factor in the reduction of the yield and test weight in the Ramona nursery in 1940, although the fly further depressed yields in susceptible strains.

RESULTS AT SPRINGFIELD

Table 3 presents summarized data for 104 strains and varieties of winter wheat grown in duplicate under outbreak conditions for infestation by Hessian fly at Springfield, Mo., in 1941, and for 87 other strains grown in single rows in a separate series. Detailed data for a few of these strains are shown in Table 1. Some susceptible varieties

**Highly significant.

showed 100% infestation in both fall and spring counts and all susceptible strains averaged high. Insufficient grain made it impossible to obtain test weights on most of the susceptible selections from Springfield so only partial analysis is possible for this factor. Fig. 2 shows one section of the nursery and clearly indicates the difference in appearance between lines resistant and susceptible to Hessian fly. Fig. 3 shows the relative yields produced by eight entries.

TABLE 2.—*Average yield and test weight of strains of winter wheat by stem rust infection classes, Ramona, Kan., 1940.*

	Infection classes in per cent							Total or average
	Trace–5	10–15	20–25	40–45	60–65	80	85–90	
				Hope Hybrids				
No. strains.....	23	3	1	0	1	1	1	30
Yield, grams....	94.9	82.8	80.5	—	66.5	37.5	66.5	89.4
Test weight, lbs.	56.1	54.6	53.3	—	46.6	47.7	51.0	55.1
				Marquillo × Tenmarq				
No. strains.....	1	3	8	9	4	1	1	27
Yield, grams....	93.5	98.8	107.7	89.7	95.5	75.5	95.5	96.7
Test weight, lbs.	58.9	59.0	58.1	58.1	55.9	54.5	55.8	57.7
				Marquillo × Oro				
No. strains.....	54	3	3	0	0	0	0	60
Yield, grams....	98.8	95.2	88.5	—	—	—	—	98.1
Test weight, lbs.	57.5	56.1	56.5	—	—	—	—	57.4
				Kawvale × Marquillo				
No. strains.....	4	0	3	0	0	0	0	7
Yield, grams....	88.9	—	109.6	—	—	—	—	97.7
Test weight, lbs.	55.4	—	55.8	—	—	—	—	55.6
				Marquillo × Minturki				
No. strains.....	1	1	1	0	0	3	0	6
Yield, grams....	115.0	86.5	78.0	—	—	66.5	—	79.8
Test weight, lbs.	53.8	54.4	54.1	—	—	51.0	—	52.6
				Miscellaneous				
No. strains.....	0	1	0	6	21	44	14	86
Yield, grams....	—	100.5	—	87.5	92.3	83.1	68.2	83.4
Test weight, lbs.	—	60.0	—	55.3	55.3	53.5	51.4	53.8
				All Strains				
No. strains.....	83	11	16	15	26	49	16	216
Yield, grams....	97.4	92.5	100.9	88.8	91.7	81.0	69.8	90.3
Test weight, lbs.	57.0	56.7	56.8	57.0	55.1	53.2	51.7	55.5

The three varieties Kawvale, Tenmarq, and Marquillo × Tenmarq 37FN1507, were represented in five replications and gave average yields of 19.5, 12.6, and 65.7 grams, respectively. The difference between Marquillo × Tenmarq and the other varieties was statistically highly significant, but between Kawvale and Tenmarq the dif-

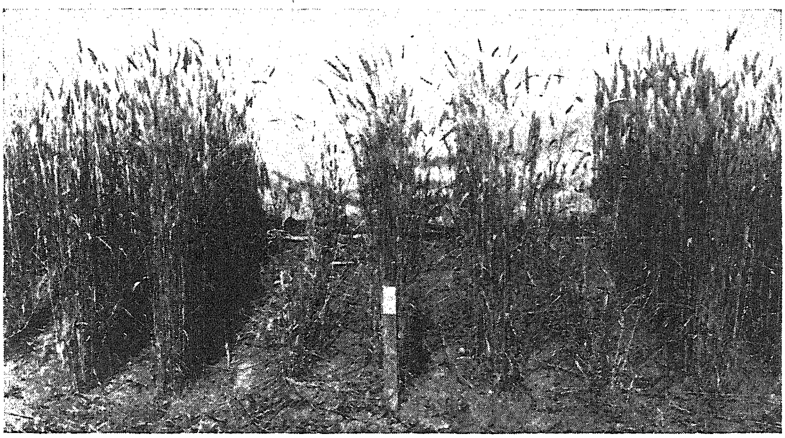

FIG. 2.—Seven strains in the nursery grown at Springfield, Mo., in 1941. Only those strains showing low infestation by Hessian fly made satisfactory yields. From left to right, the rows were planted to Marquillo × Oro (two strains), Tenmarq × Cheyenne, Marquillo × Oro (two strains), Kawvale × Cheyenne, and Marquillo × Oro.

ference was nonsignificant. The average infestation for these varieties was 91, 98, and 5% in the fall and 72, 73, and 4%, respectively, in the spring. These varieties did not differ significantly in yield at Manhattan in the absence of Hessian fly and this is further supported by unpublished experiments conducted in southeast Kansas where conditions more closely resemble those at Springfield.

A summary of all entries grown in the duplicate row series at Springfield showed that 55 strains with 20% or lower infestation in the fall gave an average grain yield of 71.4 grams; 37 strains with more than 80% infestation averaged 13.8 grams; while strains with

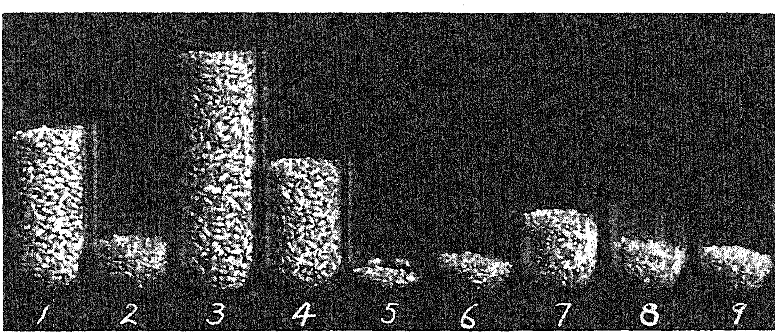

FIG. 3.—Average relative yield of grain for nine strains of winter wheat grown under heavy Hessian fly infestation at Springfield, Mo., in 1941. The strains are 1, Marquillo × Tenmarq; 2, Tenmarq; 3 and 4, Marquillo × Oro; 5, Oro; 6, Hope × Kawvale; 7, Kawvale; 8, Chiefkan; and 9, Kanred. Compare with the same strains in Fig. 1.

TABLE 3.—*Average yield for hybrids and varieties of winter wheat by Hessian fly infestation classes, Springfield, Mo., 1941.**

	Infestation classes, showing percentage of plants infested in the fall							Total or average
	0–5	6–10	11–20	21–30	31–50	51–80	81–100	
				Marquillo × Oro				
No. of strains	17	14	6	0	2	1	0	40
Yield, grams	78.0	79.1	63.9	—	55.0	59.0	—	74.6
				Marquillo × Tenmarq†				
No. of strains	8	7	4	2	2	1	0	24
Yield, grams	61.6	61.0	53.7	51.4	45.6	31.0	—	57.1
				Marquillo × Minturki				
No. of strains	0	1	2	0	1	0	2	6
Yield, grams	—	65.0	53.5	—	53.8	—	34.9	49.3
				Michigan Wonder × Marquillo‡				
No. of strains	0	0	1	1	4	10	2	18
Yield, grams	—	—	44.0	53.0	46.1	48.5	46.0	47.7
				Oro × Marquillo-Tenmarq‡				
No. of strains	1	2	3	1	1	3	5	16
Yield, grams	60.0	48.0	51.0	47.0	54.0	20.3	30.1	38.8
				Oro × (Kanred-Hd. Fed. × Marquillo)‡				
No. of strains	0	0	3	0	1	3	4	11
Yield, grams	—	—	70.0	—	36.6	37.5	6.5	35.0
				Miscellaneous Varieties and Hybrids§				
No. of strains	0	0	3‖	0	5‖	2	66	76
Yield, grams	—	—	67.9	—	49.9	12.1	12.5	17.1
				All Strains				
Total No. of strains	26	24	22	4	16	20	79	191
Weighted av. yield, grams	73.0	72.0	60.5	51.0	49.3	37.2	14.4	43.3

*The yield for each strain was based on the average grain produced in two series except as indicated.
†Seven strains were grown in the single series.
‡All strains were grown in the single series.
§Thirty-five strains were grown in the single series.
‖Marquillo hybrids.

intermediate infestation averaged 47.1 grams. Marquillo hybrids in the range from 21 to 80% infestation were few in number because these had largely been discarded in previous years in favor of more resistant selections. Michigan Wonder × Marquillo hybrids grown in the single series showed about the same yield in all infestation classes and illustrate the high degree of tolerance that was noted in other hybrids and has appeared annually in these studies. Such hybrid plants ordinarily have many fewer "flaxseed" than fully susceptible strains, indicating a fallacy in the use of percentage of plants infested without regard to the number of larvae and flaxseed

present. Further analysis is presented in summary form in Table 3. Correlation coefficients of yield and fall infestation and yield and spring infestation calculated for the duplicated series were –0.8929 and –0.8752, respectively. Both are highly significant.

The test weight was determined for as many strains as possible. Its relationship to fly infestation was somewhat vague but seemed to show a slight negative trend. The value calculated for r on 71 entries in the duplicated series was –0.1753 but was not significant. Most of the entries used in calculations were those showing some resistance to fly. The correlation might have been higher if samples representing the entire range of infestation had been available.

There was close agreement between readings of fly infestation in the fall with those made in the spring. In the duplicate series all winter varieties showing resistance in the fall also showed resistance in the spring, while in the single series only one variety, classified as resistant in the fall, showed susceptibility in the spring. The evidence shows that, in general, the strains in this test were under proportionately similar stress from Hessian fly during both seasons. It cannot be assumed, however, that spring and fall reaction are always highly correlated, for the opposite relation was indicated in certain crosses in other tests.

Damage caused by Hessian fly appears to have reduced yield in these tests because of several influences among which are death of infested tillers and plants, dwarfing, prevention of heading, interception of nutrients, and increased lodging. Resistance mechanisms exhibited by resistant strains in these tests followed the findings of Painter, *et al.* (4) in that low larval survival and tolerance were amply demonstrated. The nature of the tissues of different strains may be related in some way to these or other mechanisms involved in susceptibility (2).

The relative infestation and resulting damage at Springfield in 1940–41 was typical of results secured for several years at stations in Kansas and Missouri. Marquillo × Tenmarq 37FN1507, for example, has been in 25 separate tests during recent years and has averaged 5% infestation as compared to Tenmarq in adjacent rows which has averaged 64%. Under such conditions the yield of Tenmarq has been lower than the resistant hybrid. Resistant strains averaging 20% or less infestation by Hessian fly both in the fall and spring yielded over 5 times as much grain as an equal number of susceptible strains averaging 80% or more infestation at Springfield, Mo., in 1941–42. In another test the same year at Bennington, Kan., under very much lower intensity of infestation, resistant strains produced about 25% more grain than susceptible varieties. Known susceptible varieties in this test were only 60% infested in some cases.

DISCUSSION

Data presented in this paper demonstrate the value of inherent resistance to stem rust and Hessian fly in winter wheat in Kansas and adjacent areas in that resistant varieties are enabled to attain more nearly normal development (Fig. 4). Stem rust causes some

damage in the region almost every year and frequently threatens large areas. For this reason, more resistance is needed than now exists in commercial varieties. The use of Marquillo, Hope, and other resistant varieties or hybrids in the Kansas wheat breeding work promises ultimately to give new varieties satisfactory for commercial growing, possessing sufficient resistance to reduce or eliminate losses from stem rust. Likewise, data thus far recorded give promise of incorporating greater resistance to Hessian fly in winter wheat adapted to this region. The resistance to Hessian fly transferred from Marquillo spring wheat promises to be commercially valuable

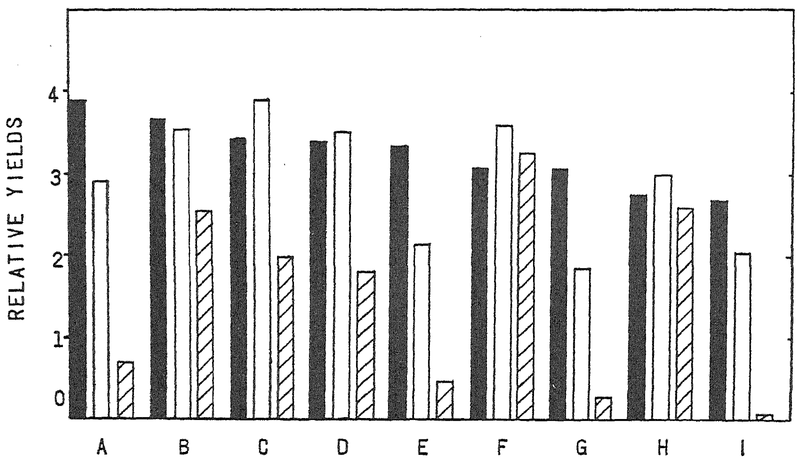

FIG. 4.—Relative yield of grain from nine strains of winter wheat grown at Manhattan (solid bars), Ramona (open bars), and Springfield (crossed bars), (see Table 1.) A, Pawnee, C.I. 11669; B, Marquillo × Tenmarq, 383397; C, Marquillo × Oro, 383442; D, Marquillo × Tenmarq, 383344; E, Tenmarq, C.I. 6936; F, Marquillo × Oro, 385628; G, Cheyenne, C.I. 8885; H, Marquillo × Oro, C.I. 11851; I, Oro, C.I. 8220.

but is inferior to some types available. Other sources being used are the American varieties Illinois No. 1 W 38 and Marvel and the foreign introductions, Renacimiento selection, IVy Gelou (C.I. 12001), IV cl÷# (C.I. 12034), and F.P.I. 94587 (durum), which promise to give a higher type of resistance in winter wheats than does Marquillo. All of these are spring varieties. Kawvale is the only variety of winter wheat which transmits some resistance to Hessian fly that has been used extensively in the Kansas breeding work. It and selected hybrids involving Kawvale are resistant in central and western areas but suffer from infestation when grown eastward.

The Marquillo hybrids emphasized so prominently in this paper are lacking in several respects, especially in winterhardiness, and must be tested more thoroughly in all respects before a final decision can be made regarding their immediate commercial value. A large number of compound hybrids and backcrosses have been made to increase the resistance of these hybrids to rusts and other diseases,

insects, and winterkilling, and to improve the yield, test weight, strength of straw, and market suitability.

SUMMARY

1. A large number of strains and varieties of winter wheat were tested in nurseries under three sets of conditions, namely, (a) generally favorable growing conditions at Manhattan, Kan.; (b) adverse conditions due mainly to stem rust infection at Ramona, Kan.; and (c) in the presence of large numbers of Hessian fly at Springfield, Mo.
2. Agronomic, stem, and leaf rust reaction and fly infestation data are presented.
3. Strains resistant to these pests gave satisfactory yield and test weight under all three of the environments. In general, susceptible varieties gave good results only at Manhattan since disease and insect injury were not serious factors.
4. While the Marquillo hybrids are not immune from rusts and Hessian fly, the resistance and tolerance appear, from these yield studies, to be of high economic importance.
5. The quantitative evidence presented proves that inherent resistance and tolerance to insects and diseases can give a considerable measure of protection to winter wheats of the central Great Plains.

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THE IMPROVEMENT OF INSTRUCTION[1]

STEPHEN M. COREY[2]

IN any program aimed at the improvement of instruction three major decisions must be made. First, those responsible for the instruction must determine what its purposes are. What changes should the course of study bring about in students? In what respects should they behave or act differently as a consequence of studying, say, agronomy. In many instances instructors have never thought carefully about the purposes of the courses they are teaching, and there is often fundamental disagreement among persons teaching the same subject.

The second decision that must be made if instruction is to be improved has to do with the learning experiences the students should have. If, for example, one of the objectives in elementary science is to bring about an understanding of the effect sunlight has upon plant growth, should we have the student (a) conduct various laboratory experiments, or (b) read certain references, or (c) observe a good demonstration, or (d) listen to a lecture, or (e) do all four? The answers to these questions regarding the relative effectiveness of this or that learning experience should be arrived at by methods other than discussion. Objective and straightforward experimental inquiries designed to solve such problems are rare but they can be made.

The third major consideration in a program of instructional improvement involves attempts to determine whether or not the behavior of the students has changed, whether or not they have learned, whether or not the instructional aims have been attained. An attack upon this problem of the evaluation or measurement of learning is frequently most fruitful of results so far as the improvement of the total instructional program is concerned. In other words, to start here usually leads to far reaching consequences.

STATING COURSE AIMS OR PURPOSES

I shall illustrate each of these three phases of an instructional improvement project by reference to the teaching of biology. As an instance of most effective thinking about the first instructional problem, an explicit statement of objectives or course purposes, the experience of a group of teachers of zoology at Ohio State University is instructive.[3] For many years zoology had been taught without any serious attempt to make definite just what the course was supposed to do to students. The text was studied, a series of laboratory exercises was completed, a number of lectures given, and very sweeping assumptions were made regarding the value of these

[1]A paper read before the Symposium on Teaching at the annual meeting of the American Society of Agronomy in St. Louis, Mo., November 11, 1942. Received for publication December 16, 1942.

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[3]BARROWS, W. M., MILLER, D. F., PRICE, J. W. Service Studies in Higher Education, Bur. of Educ. Res. Monograph No. 1. 1932. Ohio State University, Columbus, Ohio.

learning experiences to students. As a result of general dissatisfaction with the consequences of this procedure, the instructors concerned deliberated at length, conferred with their colleagues, and eventually formulated these general purposes or objectives for the first course in zoology:

1. Increasing familiarity with a fund of information about animal activities and structures.
2. An understanding of technical terminology.
3. An ability to make inferences from data—to propose hypotheses.
4. An ability to propose ways of testing hypotheses.
5. An ability to apply principles to concrete situations.
6. An ability to observe accurately.
7. An ability to use the microscope and other essential tools.
8. An ability to express effectively ideas relating to zoology.

I am not competent to judge whether these general, overall, objectives or aims are good ones or not. One aim has been omitted which any zoology instructor in college thought very important, namely, the ability to draw with meticulous care, the cross section of an earthworm. Just what the course objectives should be is a decision that must be made by the subject matter specialists after serious consideration of the student's total development. Most of us put entirely too much emphasis upon the learning of subject matter *per se*. At least so far as elementary courses are concerned, so-called subject matter is of significance only in terms of its effect upon the student. Zoological information is desirable only if it enables students who have acquired it to do better certain things that are deemed to be good.

As a second illustration of an attempt to formulate explicit, if somewhat general, instructional course purposes the following list of major aims is submitted for Bacteriology 1 as the course was taught 2 years ago by Mr. W. B. Sarles of the University of Wisconsin:

1. The learning and retention of important bacteriological information.
2. Development of the ability to draw reasonable inferences from:
   a. Experimental data.
   b. Written materials.
3. Development of the ability to observe bacteriological phenomena accurately.
4. Development of the ability to use the microscope and other essential tools effectively.
5. Development of the ability to express effectively ideas relating to bacteriology.
6. Development of the ability to follow directions in the conduction of an experiment in bacteriology.
7. Development of the ability to reproduce in a drawing what is seen.
8. Development of the ability to plan experiments by which to check bacteriological hypotheses.

9. Development of the ability to take reasonable precautions to avoid invalidation of experiments because of contamination.

10. Development of a persistent interest in bacteriological problems.

The members of your own organization have recently responded to a questionnaire which requested them to state the objectives that should be attained in an elementary course in agronomy. In the summary of these data that Mr. Graber was kind enough to send to me, I did not note any thorough and systematic analysis of course purposes. Many excellent single aims, however, were stated. Among these were:

1. To recognize and analyze basic problems in field crop production and to apply principles to their solution.

2. To teach well a few big understandings rather than a confusing welter of disconnected facts.

Eventually, any description of course purposes must be sufficiently detailed and analytical to give a very definite idea of the exact effect the course will have upon students. General purposes, such as those given above for elementary zoology and bacteriology, must be broken down until specific "ways of behaving" are described. The ultimate purpose of most instruction, especially instruction of a practical sort, is to change the behavior of students, to make them act differently.

For example, you will recall that one of the general aims of the zoology course described above was to develop the ability to use the microscope. This involves (a) the ability to use the adjustment screws properly; (b) the ability to regulate the light by the use of the mirror or diaphragm; (c) the ability to place the microscope properly with respect to table, body, windows, etc.; (d) the ability to locate the object within certain time limits; (e) the ability to use the eyes most effectively, that is to keep them both open, etc.

The necessity for a clarification of course aims would not need to be elaborated were it not for the fact that most of us admit the importance of such activity and let it go at that. Or equally bad, we make a general statement of course purposes and then forget the matter. Many instructors are nonplussed when students ask, in all sincerity, "What is the big idea of this course anyway? What's it supposed to do to us or for us?" I know because students have asked me that question and frequently I have not known the answer. Under such circumstances I am apt to bluster a bit and refer to a textbook which is used or resort to some other strategem. I have worked with numerous instructors as they were attempting to formulate more definitely the purposes of the course they were teaching, and the experience is a very salutory one. An intelligent description of a course becomes then not a mere enumeration of the topics to be covered but rather a clear statement of the changes it is hoped that the course will bring about in students.

SELECTING GOOD LEARNING EXPERIENCES

Once the purposes of the course have been stated in detail, the second responsibility of those concerned with the improvement of

instruction is to describe the learning activities or experiences that will lead to the attainment of these purposes. There are many things that students can do to learn, but college and university instructors avail themselves of but very few—chiefly reading, listening to lectures, and working in a laboratory. Referring again to your description of your own practices in the teaching of agronomy, practically every institution reporting employed the reading-lecture-laboratory method of instruction exclusively.

No one can know in advance what sort of learning activity or learning experience will lead to the fulfillment of a certain purpose most quickly. Such a question can only be answered definitely by continuous, pedagogical research.

Despite this fact, and in the absence of any great amount of objective data to support the contention, the practice of teaching by lecturing has little *a priori* justification. In most cases students soon learn that they can *either* take careful notes on lectures or read the textbook. American college practises would probably be greatly improved if the *informational* lecture were dispensed with. The information could be mimeographed so that students might read it and the instructors could then spend their time answering the inevitable questions that arise.

To illustrate the relationship of learning experience to the objectives, assume that the instructors in a course have decided that one of their objectives will be to familiarize students with a rather large body of known facts in the field of agronomy. So far as this purpose is concerned, a variety of learning activities might be recommended, to wit:

1. Students might be asked to listen to lectures and observe demonstrations.
2. Students might be asked to study a text and outside readings.
3. Students might be asked to do both.
4. Students might be asked to do either or both with a weekly conference with a quiz master.

These suggestions regarding types of learning experience are very general and are susceptible to many variations. Several years ago I worked with a teacher of bacteriology who was considering undertaking some pedagogical experiments in his elementary course. One of the ventures discussed involved an arrangement whereby superior students would not be expected to come to lectures. They were to be given lists of readings and were to attend quiz sections if they thought that necessary, but their learning was to be achieved largely without the assistance of a professor. Nothing came of this particular project, but its design would have yielded at least a partial answer to an important inquiry. If the highest 20% of our students can learn as effectively on their own, so to speak, why not let them do so? We could then spend more time helping the other four fifths.

Very often, a critical examination of stated course purposes as well as the instructional procedures employed to attain them reveals striking and apparent inconsistencies. I have recently examined the laboratory manual used in a college biology course in which the in-

structor claimed that much emphasis was placed upon teaching students to solve problems. One of the primary course purposes was to enable students to develop and test hypotheses about biological phenomena.

Despite this clearly stated purpose, the laboratory manual allowed students no opportunity to do any scientific thinking. In the case of every so-called experiment, the procedure to be followed was stipulated in such great detail that a student who went through the steps had to come out with the right answer. He got no experience formulating and testing hypotheses. Insofar as this was true, the course *purposes* and *procedures* were clearly incompatible.

MEASURING THE SUCCESS OF INSTRUCTION

The third aspect of any program of instructional improvement involves measuring the progress students have made toward the course objectives. As was stated above work upon this problem has been most fruitful of results. At the present time the conventional course examination represents little more than an attempt to measure how much information a student is able to reproduce, or in the case of the objective examination, to recognize. This is true despite the fact that no one would claim that the only, or even the chief, purpose of a course is to cram a student's memory with information. Students, however, are realistic and they have admitted many times that they try to learn so as to get good grades on examinations. In other words, the examination operates very effectively to direct the student's learning. This fact cannot be overemphasized. One of the best ways to find out what an instructor is actually teaching is to examine his examinations.

In connection with our tendency to measure the retention of facts only, R. W. Tyler, now at the University of Chicago, conducted an interesting series of investigations a few years ago.[4] In some 16 University courses he constructed two quite different types of examinations. The first measured the ability to *recall* information which should have been learned in, say, elementary botany, and the second measured the ability to recall *and* apply to new situations this same information. The second ability is undoubtedly more inclusive and more important. Our examination practices imply that we believe any student who remembers a vast store of information can also make it function in new situations. Tyler's two examinations were given to the same students which made it possible to determine whether or not persons who remember a great deal were also able to use what they remembered. His investigation involved over 3,500 students and the median coefficient of correlation between the two abilities was + .37. One way of interpreting the results is to say that of 100 students who were above average with respect to the recall of information, 38 of them were below average with respect to the ability to use this information in new situations. We err, in other words,

[4] JUDD, C. H., *et al.*, Education as Cultivation of the Higher Mental Processes. New York: The Macmillan Co. 1936. (Chapter 2.)

when we assume that students who can repeat much information can also use this information to solve problems.

If we as teachers want students to move in the direction of objectives such as the ability to make valid inferences from data, the ability to apply scientific principles to concrete situations, or the ability to observe accurately, we must develop examinations that measure these abilities. This can be done with a considerable degree of satisfaction. For example, Professor Sampson of the department of Botany at Ohio State University wanted to measure the ability of his students to make reasonable inferences from specific experimental data.[5] His first step was to collect descriptions of situations such as the following, which students would read and from which the inference would be made:

A number of barley plants were grown in soil low in nitrates. It was found that the tops weighed five times as much as the roots. At the same time similar barley plants were grown in soil containing an abundance of nitrates. In this case the tops weighed nine times as much as the roots.

Students were then asked to make inferences from these data and from these inferences objective test items were constructed. Here is an illustration taken from a long list of similar questions involving many types of information:

Given data.—A grain of corn was placed upon moist blotting paper in a warm (20° C) dark room. Another grain of corn was placed upon moist blotting paper in a warm (20° C) sunlit room. Both seeds germinated (that is the embryo plant within the seed began to grow).

Inferences.—Check each one that is completely supported by the facts given above:

1. A grain of corn must be placed in moisture in a warm room to germinate.
2. Light has no effect upon the germination of seeds.
3. Seeds of corn will germinate either in light or in darkness if other conditions are favorable.
4. Heat and moisture are necessary for germination but light is not.
5. Light is not necessary for the germination of seeds of corn.
6. Moisture causes seeds to germinate.
7. Moisture is necessary for germination.
8. Seeds need heat to germinate.
9. Growth may occur in darkness.
10. Heat and moisture promote growth.

The correct generalizations in this illustration are not difficult for you to recognize, but using the same method questions can be made which involve considerable understanding of the relationship between concepts in the subject involved. The ability to make these reasonable generalizations is very important and, incidentally, is retained by the student for a much longer period of time than are the specific facts on which the generalization is based.

Speaking in general about the field of agronomy, examination questions and procedures should probably make possible the answers

[5]See footnote 4, Chapter 1.

to these three questions: (1) Do the students know the facts about field crops? (2) Do they understand the relationship among these facts, have they developed the ability to generalize and to apply principles to new situations? (3) Are they disposed to do anything about it?

This last question, I presume is the most important one and yet our tests rarely provide an answer to it. It is one thing for a farm lad living around Rockford, Ill., to know that alfalfa often does better on soil that has been limed. This, I understand, is a fact. Quite a different ability is involved when he can explain why alfalfa on the north side of east and west crushed rock roads in Illinois is often taller. The most important consequence of agronomical instruction in this connection, however, would be the actual liming of soil when it needs it. This is the acid test of instructional effectiveness and we rarely make it.

In my judgment it is not possible to undertake a continuous program for the improvement of instruction without making provisions for research. The last word is never uttered. Agronomy departments might do a great deal for their science in the long run by occasionally encouraging instructional research for those of their candidates for the Ph.D. degree who plan to teach. In terms of the ultimate utility of their research training, too, careful work on the improvement of their instruction will be of much greater value to some graduate students than intensive research within a narrow field of subject matter. The value to the university providing opportunity for this pedagogical research will be appreciable also. An incidental benefit will be the better preparation students will receive in undergraduate courses the mastery of which is prerequisite to research achievement.

EVALUATING TEACHING EFFECTIVENESS

In conclusion I would like to speak briefly about the evaluation of teaching effectiveness. This, of course, is an integral part of any program to improve instruction. The venerable method of appraising the worth of a teacher has been for some mature person to enter his class and watch what he does. This method rather completely misses the point. It is as if we were to evaluate a method of traffic control in a given city by watching the policeman rather than the traffic. In a teaching situation we should watch the learners. It is their progress which indicates whether the instruction is good or poor. If two groups of students are comparable, and group "A" makes more rapid progress toward the various course objectives than group "B", then the instructor in course "A" is doing a more effective job. This assumption of comparability among students is a bit hazardous, but we do it implicitly whenever we compare teachers.

If we wish to evaluate the success of instruction by observing the learning of students, the need for valid measuring instruments to appraise progress toward course objectives is apparent. There is an increasing realization in college circles of the necessity for having good examinations if much is to be known about teaching. The construction of good examinations calls for a considerable amount of technical skill and consequently costs money.

In the last analysis the persons who can work most effectively improving instruction in a certain course are those engaged in teaching it. With relatively few exceptions, however, the rewards for efforts so expended have in the past been very meagre. The recognition which comes to the graduate assistant or instructor, or professor, for that matter, who is sufficiently engrossed in his teaching to work hard at it is not appreciable. Research is the thing. It is probable that we get just such teaching as we deserve. Many staff members with high rank are indifferent to problems of instruction and are convinced that anyone who has mastered his subject can teach. I know of no evidence for this belief. Certainly sound scholarship is essential for good instruction, but it does not constitute any guarantee.

Successful teaching is a function both of willingness to work as well as an understanding of the three basic instructional problems that need to be worked upon. An attractive personality helps a teacher in that it implies tact and an understanding of the subtleties of successful human intercourse, but the possession of personal magnetism is not an unmixed blessing. The temptation too frequently is to let personal charm substitute for teaching effectiveness. Students themselves cannot disentangle their affection for a teacher from their judgment regarding his instructional efficiency. Each is important and neither should be mistaken for the other.

To try to deal with the whole problem of instructional improvement at any one time is apt to lead to few changes. If the matter is thought to be of sufficient importance to warrant hard work and recognition on the part of a group of instructors teaching a single course, their staff meetings might be devoted throughout one semester to a formulation of the basic understandings to be taught. Another semester might be devoted to the construction of valid objective tests. Still another to descriptions of complete learning situations which might later be evaluated as to their effectiveness. Usually, group cooperation on course improvement, if recognized by persons occupying major positions as a worthwhile activity, proves to be a very stimulating and productive experience. The benefits to the institution making arrangements for such cooperation are incalculable.

A SYMPOSIUM ON AGRONOMIC TEACHING

THE symposium was held on November 11, 1942, at the annual meeting of the American Society of Agronomy in St. Louis, Missouri. Your committee made a study of the introductory course in field crops by sending an inquiry to agronomy departments of all the colleges of agriculture in the United States. This study was presented and discussed at the symposium following the paper by Dr. S. M. Corey (pages 230 to 237). The results of the study are briefly summarized as follows:

The enrollment in the introductory course on field crops is comprised primarily of freshmen and sophomores in 39 departments of agronomy in the total of 48 colleges of agriculture contacted. It is required of all or nearly all agricultural students in 33 departments and is a required course for certain majors in 12 departments. The introductory course has an important place in the college curricula.

Laboratory work is a required part of the course in 40 departments. The lecture and laboratory are given as separate courses in only one department. The lecture-laboratory-recitation type of presentation is the most commonly used method of teaching. The laboratory work as reported by 32 departments is predominantly of the type which includes seed identification, grading, judging, commercial seed testing, seed cleaning, field trips to experimental plots, taxonomy, and botanical characteristics. In two departments emphasis is placed on the morphology of agronomic plants to show application to farm problems, identification of legumes and grasses by vegetative and floral characteristics, industrial utilization, and quality studies.

A textbook is required in the beginning course in field crops in 33 departments, a laboratory manual in 9 departments, and mimeographed material is used in 24 departments. In 42 replies to the question, "Do you substitute demonstrations, including lantern slides, movies, or film strips for certain laboratory exercises?", it was indicated that such illustrative materials are purely supplementary and not a desirable substitute for live material.

Less than 50% of the students enrolled in the beginning course in field crops in 16 departments have had botany or take it concurrently, whereas in 25 departments more than 50% of the students enrolled in field crops have had botany or are taking it concurrently. Students enrolled in the beginning course without previous or concurrent course work in botany were reported from only two departments.

More than 50% of the students enrolled in the beginning course in field crops in 27 departments have had no Smith-Hughes or high school agriculture, whereas more than 50% of the students enrolled in the beginning course in field crops in 16 departments have had Smith-Hughes or high school agriculture.

More than 50% of the students enrolled in the beginning course in field crops in 8 departments have had no farm experience, whereas more than 50% of the students enrolled in the beginning course in field crops in 36 departments have had farm experience.

Emphasis as to the objectives to be achieved in the beginning course in field crops appears to be about equally divided between (1) acquainting the students with the best agronomic practices in the production of crops and pasturage, (2) giving the students a knowledge of the principal agronomic problems and their solution and to present a survey of agronomic data pertinent to them, and (3) presenting in an abbreviated but integrated manner the elementary principles of plant physiology, morphology, pathology, ecology, and heredity as a basis for understanding agronomic practices and problems.

WAR AND POST-WAR ADJUSTMENTS

An additional inquiry as to student enrollment and as to war and post-war adjustments in teaching agronomy was submitted to all the agronomy departments in the United States.

A substantial reduction in student enrollment in all courses has occurred, but particularly in courses for upperclassmen and graduate students. However, at the beginning of the school year in the fall of 1942 most departments had found it unnecessary to drop courses because of insufficient enrollment.

Of 36 departments reporting only 4 found it necessary to discontinue courses temporarily because of inadequate staffs. In most institutions student reduction has kept ahead of staff reduction.

Little has been done to make marked changes in courses as a result of the war except to orient the work to the war situation, reduce sections, and to encourage greater discussion in the laboratory. Most departments believe that from five to six students should be the minimum enrollment for giving a formal course for upper classmen.

A few departments are using research workers to aid in teaching agronomy. Such a shift naturally is conditioned by the source of research funds and administrative restrictions pertinent to the individual institution.

Most departments have not considered special training of students for foreign agricultural service after the war, but 10 departments indicate that they are considering such courses.

Nearly all departments express the belief that a study should be made to ascertain the need for the training of specialists for foreign agricultural service in the counsellor, commercial, and other foreign relations. Doubtless this subject merits consideration by the Society and it was suggested that a committee be appointed to investigate the problems involved. Subsequently the matter was referred to the committee on the American Society of Agronomy and the War.

Mimeographed reports on the two studies aforementioned are still available and can be obtained from the Chairman of the Committee.

COMMITTEE ON SYMPOSIUM ON AGRONOMIC TEACHING

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BARLEY VARIETIES REGISTERED, VIII[1]

H. K. HAYES[2]

FOURTEEN varieties of barley have been approved for registration previous to this report. Three registered varieties were described in the last report.[3]

SANTIAM, REG. NO. 15

Santiam is a selection from Composite Cross C.I. 5530 made by the U. S. Dept. of Agriculture and involving a number of winter type varieties. It was developed and distributed by the Oregon State College. The name of the breeder and introducer is D. D. Hill. Mr. G. A. Wiebe of the U. S. Dept. of Agriculture supplied the following description of Santiam barley: "Winter type habit of growth. Six-rowed spike, hulled kernel, white, rough awned and long haired rachilla."

The variety was first distributed in 1939, its superior characters being high yielding ability and winterhardiness under western Oregon conditions. Yields at Corvallis, Ore., for a 7-year period are given in Table 1.

TABLE 1.—*Comparative yields in bushels per acre of Santiam, Winter Club, and Tennessee Winter, in 1/40-acre plot trials with three replications at Corvallis, Ore.*

Variety	Yields in bushels per acre							
	1934	1935	1936	1938	1939	1940	1941	Av.
Santiam	38.2	72.0	34.7	41.3	84.3	56.2	53.8	54.4
Winter Club	24.7	74.4	39.3	42.9	80.9	58.4	36.7	51.0
Tennessee Winter	36.1	56.6	30.1	31.3	—	—	—	—

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 14, 1942.

[2]Chief, Division of Agronomy and Plant Genetics, Department of Agronomy, University of Minnesota, St. Paul, Minn. Member of committee on Varietal Standardization and Registration of the Society charged with the registration of barley varieties.

[3]HAYES, H. K. Barley varieties registered, VII. Jour. Amer. Soc. Agron., 34:281–282. 1942.

REGISTRATION OF IMPROVED COTTON VARIETIES, III[1]

H. B. BROWN[2]

REPORTS on the registration of improved cotton varieties were published in this JOURNAL in December, 1936, and in January, 1940. An application for the registration of Bobshaw cotton was received in July, 1941, but due to the fact that the registration was to be based largely on fiber quality the Cotton Sub-committee felt that it should make a careful study of the fiber qualities of this cotton before approval of its registration. Results from additional studies made by the Committee substantiated claims made by the applicant so the application was approved, the variety to be known as Bobshaw and given registration No. 36. Below is a brief history and description of the variety.

BOBSHAW, REG. NO. 36

Bobshaw, formerly known as Stoneville A-64-7, originated from a plant selection made at Heathman, Miss., in 1936 by John W. Oakley, cotton breeder for the Robertshaw Company, Heathman, Miss., in a field of Stoneville cotton. Following the selection, the strain was tested by the breeder and by experiment stations in several states for 5 years. Experiment station tests showed that the proposed new variety ranked high in production and fiber analyses showed superior fiber qualities. The tensile strength ranged from 840 to 864 units (Pressley machine); fineness, 2,500 to 2,800 units (Hertel machine); and uniformity, 83 to 86 (Hertel machine).

Under average growing conditions, the plants are 3 to 4 feet tall, symmetrical, and moderately open. There are from one to three small vegetative branches and numerous, well-developed, well-distributed fruiting branches. Stems are slightly pubescent; leaves medium sized, medium dark green, and slightly pubescent. Flowers are medium sized and pale cream to white in color; bolls are medium sized, ovate, short pointed, 70 to 85 per pound of seed cotton; staple length 1 to $1\frac{1}{16}$ inches; lint percentage 35 to 38. Seeds are moderately small, fuzzy, and light gray in color; seed index, 11.1 grams for 100 seeds. Wilt resistance is but medium. It is a medium early cotton with fluffy, open bolls that pick well.

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 14, 1942.

[2]Agronomist, Louisiana Agricultural Experiment Station, Baton Rouge, La., and a member of the 1942 Committee on Varietal Standardization and Registration, charged with the registration of cotton varieties.

REGISTRATION OF VARIETIES AND STRAINS OF OATS, XII[1]

T. R. STANTON[2]

SINCE the publication of the eleventh consecutive report (7)[3] on the registration of improved oat varieties in March 1942, two additional varieties, listed and described in the paragraphs that follow, were submitted and approved for registration:

Group and Varietal Name	Reg. No.
Midseason yellow:	
DeSoto	101
Midseason white:	
Bridger	102

DESOTO, REG. NO. 101

DeSoto (C.I. 3923)[4] (Ark. Sel. No. X-2-25-10-1) originated from a cross (XS1110) between Lee (C.I. 2042) and Victoria (C.I. 2401) oats made in the greenhouse at the Arlington Experiment Farm, Arlington, Va., by T. R. Stanton in the spring of 1931 (2). The F_1 and F_2 generations were grown at the Aberdeen Substation, Aberdeen, Idaho, in 1931 and 1932. The seed from about 550 F_2 plants was threshed in bulk and distributed to several experiment stations, including the Rice Branch Station, Stuttgart, Ark. C. Roy Adair, who selected and developed DeSoto from this F_2 material at that station, submitted with the application for registration the following statement on its breeding:

F_3 line X-2-25, which proved to be fairly uniform, was selected in 1933 and grown in a 5-foot row in 1934. It was grown in a single 3-row plot in 1935, and in nursery yield experiments in the years 1936 to 1939. A selection, No. X-2-25-10-1, very similar to the F_3 line, was made in 1937. This selection was grown in a 2-row, 10-foot plot in 1938, in a preliminary yield nursery in 1939, in an advanced nursery in 1940, and in field plots in 1941–42. This reselected strain, now named DeSoto,[5] was increased in 1941 and 1942.

Dr. Adair described DeSoto as follows:

The growth habit in the fall and winter is semiprostrate, similar to that of Appler (Red Rustproof). The amount of growth during the fall, winter, and early spring is slightly greater than that of Appler. The foliage is a dark, yellowish green with a bluish-white bloom on the culms. The plants tiller abundantly. The culms are short and slender but do not lodge under average conditions.

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[1]Registered under cooperative agreement between the Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 28, 1942.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture, and member of the 1942 Committee on Varietal Standardization and Registration, charged with the registration of oat varieties.

[3]Reference by number is to "Literature Cited", p. 244.

[4]C.I. refers to accession number of the Division of Cereal Crops and Diseases.

[5]The variety was named for the early Spanish explorer De Soto, hence the spelling "DeSota" in a previous publication (3) is erroneous.

The grain is light red, and the spikelets usually have only two florets. Some of the grains have awns, the rachilla segment remaining with the secondary grain on separation from the first. The latter has basal hairs and separates from its pedicel by abscission, leaving a small "suckermouth" or basal scar.

This variety is resistant to crown rust, smut, and cold.

DeSoto was developed cooperatively at the Rice Branch Experiment Station (Stuttgart) by the University of Arkansas, College of Agriculture, Agricultural Experiment Station, and the Bureau of Plant Industry. It was first distributed for growing on farms in the fall of 1942.

The annual and average yields from nursery plots at Stuttgart, compared with those of Lee and Ferguson 922 (Red Rustproof), are given in Table 1. For further information on DeSoto, see Adair (1), Murphy, Stanton, and Coffman (3), and a mimeographed report by Adair.[6]

TABLE 1.—*Yields of DeSoto, Ferguson No. 922, and Lee oats grown in nursery and field plot trials at Stuttgart, Ark., 1935 to 1942, inclusive.*

Variety	C. I. No.	Acre yield, bushels								Average		
										1935–42	1941–42	
		1935	1936	1937	1938	1939	1940	1941	1942	Nursery	Nursery	Field plots
DeSoto*	3923	59.4	43.4	62.4	12.9	67.3	86.2	119.4	65.2	64.5	92.3	65.8
Ferguson No. 922	2150	52.9	48.8	49.2	21.5	71.4	77.8	96.2	48.7	58.3	72.5	58.5
Lee	2042	3.6	46.8	42.0	4.8	81.3	81.7	33.4	33.4	40.9	33.4	34.6

*Yields for the years 1935–39 are for the selection X-2-25; the yield for the year 1940 is for the similar selection X-2-25-10-1; and yields for the years 1941 and 1942 are for the identical reselection X-2-25-10-1-1.

BRIDGER, REG. NO. 102

Bridger (C.I. 2611) originated from a cross between Markton and Victory oats made by G. A. Wiebe at the Aberdeen Substation, Aberdeen, Idaho, in 1923. This cross also gave rise to Bannock and Huron, previously registered improved varieties (5, 6). Some of the more promising selections from this cross that had been resistant to smut at Aberdeen were sent to the Montana Agricultural Experiment Station at Bozeman in 1929, where they were tested from 1929 to 1941. Selection C.I. 2611 proved to be outstanding for quality, stiff straw, resistance to smut, and produced satisfactory yields. It was named Bridger, increased, and distributed in 1941 by that station for growing under irrigation. It is a product of cooperative research between the Division of Cereal Crops and Diseases, Bureau

[6]Experiments with winter oat varieties, 1941–42. Univ. of Ark., Col. of Agr., Agr. Exp. Sta., Rice Br. Sta. (Stuttgart). (Unnumb. pub.) (Mimeographed Aug. 1942.)

of Plant Industry, and the Montana and Idaho experiment stations. Many workers had a part in its development.

The application for registration of Bridger was submitted by Royse P. Murphy, who furnished brief descriptive notes on the variety.

Bridger is a tall, midseason to late variety of the sativa type with spreading panicles and rather short, plump, white kernels. It is resistant to lodging and has the smut resistance of Markton.

The 9-year annual and average yields of Bridger, Victory, and Markton, grown in replicated field plots at Bozeman, are given in Table 2.

TABLE 2.—*Yields of Bridger and the two parental varieties of oats at Bozeman, Mont., 1933 to 1941, inclusive.*

Variety	C. I. No.	Acre yield, bushels									Av.
		1933	1934	1935	1936	1937	1938	1939	1940	1941	
Bridger....	2611	147.9	142.6	143.5	104.4	145.8	142.9	137.7	133.0	131.3	136.6
Victory....	560	133.4	139.7	160.4	124.9	116.7	137.1	137.1	127.8	149.4	136.3
Markton..	2053	134.2	147.3	152.9	126.0	148.8	138.8	125.4	124.3	139.4	137.5

Bridger combines the high quality of Victory with the smut resistance of Markton. It is equal in yield and superior to both in stiffness of straw. For further information on Bridger see Schlehuber, Sturm, and Bamberg (4), and also mimeographed reports by Coffman.[7]

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[7]COFFMAN, F. A. Results from the cooperative coordinated oat breeding nurseries for 1939 and the uniform winterhardiness nurseries, 1939–40, U. S. Dept. Agr., Bur. Plant Ind., Div. Cereal Crops and Dis. [Unnumb. Pub.] Sept. 15, 1940. (Mimeographed.)

REGISTRATION OF IMPROVED WHEAT VARIETIES, XV[1]

J. ALLEN CLARK[2]

FOURTEEN previous reports present the registration of 64 improved varieties of wheat. In 1940, two varieties were registered.[3] No varieties were registered for the crop year 1941. Two varieties have been approved for registration in 1942. These are:

Varietal Name	Reg. No.
Pawnee	330
Comanche	331

PAWNEE (REG. NO. 330)

Pawnee (Nebr. No. 1086, C.I. 11669) was developed in cooperative experiments of the Nebraska and Kansas agricultural experiment stations and the Division of Cereal Crops and Diseases, Bureau of Plant Industry. It is the result of a Kawvale × Tenmarq cross made at the Kansas Agricultural Experiment Station, Manhattan, Kans., in 1928. The F_1, F_2, and F_3 generations of the cross were grown at Manhattan, and in the fall of 1931, 52 F_3 plant selections were sent to the Nebraska Agricultural Experiment Station where they were grown, studied, re-selected, and the best strains advanced to yield tests. Because of outstanding performance in Nebraska, the selection now known as Pawnee was entered in cooperative nursery yield tests through the Southern Great Plains in 1935. It also has been tested in plot experiments at Lincoln, Nebr., since 1936. Application for registration was made by the Department of Agronomy, Nebraska Agricultural Experiment Station.

Pawnee is a winter wheat with glabrous, white glumes, awned spike, and hard red kernels. It is earlier than either of its parents, carries moderate resistance to bunt, is resistant to Hessian fly, in the hard winter wheat region, is highly resistant to loose smut, has some resistance to leaf rust, and is either slightly resistant to or able to escape severe stem-rust damage. The test weight per bushel is heavier than Turkey, but the grain is inclined to be somewhat lighter in color. The milling and baking characteristics indicate that, while Pawnee is not outstanding for quality, it is nearly equal to Turkey. The variety is slightly less winter hardy than Turkey or Kharkof, has a tendency to shatter, but in yield tests over a wide area has been consistently high in both nursery and plots. Yield data at Lincoln, Nebr., are presented in Table 1.

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[1]Registered under a cooperative agreement between the Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication February 8, 1943.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture. Member of the 1942 Committee on Varietal Standardization and Registration of Wheat Varieties of the American Society of Agronomy.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, XIV. Jour. Amer. Soc. Agron., 33:255–256. 1941.

The variety has been tested thoroughly in the cooperative winter wheat improvement project in both nursery and plots throughout the central and southern Great Plains. Based on these tests, Pawnee

TABLE 1.—*Annual and average yield in field plots of Pawnee and three standard varieties at Lincoln, Nebr., 1936–42, inclusive.*

Variety	Yield, bushels per acre							Average
	1936	1937	1938	1939	1940	1941	1942	
Pawnee (new).......	32.7	14.1	20.6	22.7	22.7	29.8	55.9	28.4
Cheyenne (standard)	31.8	14.0	13.7	22.7	19.4	18.4	45.9	23.7
Nebred (standard)...	34.2	12.8	17.7	19.3	15.1	20.7	41.2	23.0
Turkey (Nebr. No. 1)	31.4	14.6	12.7	20.0	17.9	15.4	40.9	21.8

TABLE 2.—*Agronomic data for Comanche and three standard varieties grown in triplicated 1/40-acre plots, Manhattan, Kans., 1937–41, inclusive.*

Variety	C.I. No.	Date headed	Height, inches	Test weight, lbs.	Yield per acre, bu.
Comanche (new)....	11673	May 16	37	57.7	29.2
Tenmarq (standard)	6936	May 18	39	57.0	26.5
Blackhull (standard)	6251	May 18	40	58.5	25.3
Turkey (standard)..	1558	May 21	39	56.6	22.9

TABLE 3.—*Average yields for Comanche and other winter wheat varieties tested in Kansas for all or part of the years 1937–41, inclusive.*

Station and years	Average yield of varieties, bu.			
	Turkey C.I. 1558	Blackhull C.I. 6251	Tenmarq C.I. 6936	Comanche C.I. 11673
Manhattan, 1937–41..........	22.9	25.3	26.5	29.2
Hays, 1938–41...............	18.1	19.5	24.8	26.9
Garden City, 1939–41..........	11.9	12.6	15.5	17.4
Tribune, 1939–41.............	13.1	16.9	19.1	19.0
Colby, 1941..................	33.2	32.5	38.6	37.5
Wichita, 1938–41.............	27.4	28.0	32.6	35.9
Kingman, 1938–41............	20.3	20.1	23.6	25.5
Hutchison, 1939–41...........	20.7	23.0	24.3	27.3
Dodge, 1939–41..............	23.0	24.3	27.7	31.2
Northcentral Kansas, cooperative experiments, 1941.......	28.2	24.4	31.0	30.3
Southcentral Kansas, cooperative experiments, 1941.......	23.4	23.2	30.3	32.5
Northwest Kansas, cooperative experiments, 1941...........	16.7	15.2	19.3	19.3
Southwest Kansas, cooperative experiments, 1941..........	22.2	21.0	31.8	33.3
Weighted average...........	20.8	21.9	25.5	27.5
Test weight, lbs., weighted average......................	56.0	57.6	56.4	57.5

should be of most value to Nebraska and Kansas, since it has been most outstanding in these states, although it also has done well in experiments in Oklahoma and Texas. It was released for distribution in the fall of 1942.

COMANCHE (REG. NO. 331)

Comanche (Ks. No. 2729, C.I. 11673) was developed by the Kansas Agricultural Experiment Station in cooperative experiments with the Division of Cereal Crops and Diseases, Bureau of Plant Industry. The Nebraska, Oklahoma, Texas, Colorado, Wyoming, and Minnesota agricultural experiment stations cooperated in testing this variety in comparison with others in the hard red winter wheat region.

Comanche is the result of a selection made in the F_5 generation from an Oro (C.I. 8220) × Tenmarq selection (Ks. 2637) cross made at Manhattan, Kans., in 1928. The F_1 and F_2 plants and F_3 lines were grown in the Agronomy Department plant breeding nursery. Additional selections were made from special bunt-resistant material in the Botany Department nursery in the F_4 and F_5 generations. The first yield tests were made in the Agronomy Department nursery in 1934. It was advanced to rod rows in 1935, to field plots in 1936, and was included in the uniform yield nursery at nine stations in five central and southern Great Plains states in 1937, and in uniform

TABLE 4.—*Yields of Comanche and other winter wheat varieties for Oklahoma and Texas stations, 1938–41, and test weight for the southern district, 1940–41.*

Location and years	Kharkof C.I. 1442	Blackhull C.I. 6251	Tenmarq C.I. 6926	Comanche C.I. 11673
Average Yield, Bushels per Acre				
Oklahoma, 4 stations, 1938–41, 10 station-years	25.8	26.6	28.2	30.9
Texas, 4 stations, 1938–41, 12 station-years	15.6	17.7	19.0	20.3
Average Test Weight in Pounds				
Southern District, 8 stations 1940–41, 12 station-years	54.5	56.8	54.6	56.3

TABLE 5.—*Average disease reaction of Comanche and other varieties tested under artificially induced epidemics at Manhattan, Kans., during the years 1937–41, inclusive.*

Variety	C. I. No.	Bunt, %	Leaf rust, %	Stem rust, %	Loose smut, %*
Comanche (new)	11673	1.5	20	41	4
Nebred (standard)	10094	3.2	87	69	5
Tenmarq (standard)	6936	38.1	53	77	2
Chiefkan (standard)	11754	71.4	60	59	8

*For 1940 only. Natural infection.

plot tests at 13 stations in 1938. Extensive tests throughout the region have been continued to the present time. Summaries of the data upon which registration is based are shown in Tables 2 to 5.

Comanche is a hard red winter wheat. Its superior characteristics are high yield, good test weight, earliness, stiff straw, milling and baking quality equal to Turkey, high resistance to many important races of bunt, considerable resistance to leaf rust, and more tolerance to stem rust than other varieties now grown in the area. It is susceptible to loose smut and Hessian fly and possesses only moderate winterhardiness and, therefore, cannot be expected to be a satisfactory variety north of the area where Blackhull and Tenmarq do well. It was released for distribution in the fall of 1942.

INFLUENCE OF VARIETAL DIFFERENCES ON THE GRADE OF COTTON[1]

H. B. Brown and C. B. Haddon[2]

IT is the general impression of students of the problem that the grade of lint cotton is determined mainly by the amount of exposure that the open bolls receive in the field and by the care taken in picking and ginning the cotton. There have been indications, however, that certain varieties give a lower grade than others when grown and handled in the same way. Some growers have contended that they get better grades from certain varieties than from others. It is also a talking point with some seed salesmen that their variety or varieties give a better grade of lint cotton than the average.

Since a brief survey of cotton literature showed but little definite data on the effect of variety on grade, a project was started by the Louisiana Experiment Station in 1939 in an effort to obtain more information on the subject.

METHODS USED

The research was divided into two divisions. First, studies in which bale lots of cotton were used and ginned on a modern gin with complete cotton cleaning equipment. Second, studies of small-scale operations in which several varieties grown on small replicated plots were used and ginned on a small saw gin not equipped with cleaners.

The first division of the work was carried on on alluvial or delta land at St. Joseph, La. A 12-acre field was divided into acre plots, four of which were planted in Delfos-531 cotton, four in Stoneville-2B, and four in Delta-pine, these being the three most extensively grown varieties in the state. This provided for a bale of cotton of each variety at each of three or more pickings. One picking was made fairly early in the season, one at midseason, and one late, care being taken to see that the same pickers worked on all varieties and that the varieties were all handled in the same way throughout the entire process of planting, cultivating, picking, and ginning. Ten lint samples of each bale were taken from the pressbox while the bale was being ginned and one was taken from each side of the bale after it came from the pressbox.

The small-scale studies were conducted on terrace land soil at Baton Rouge, La., where rains were frequent during July and August. Eight row plots of each of six prominent varieties grown in the state were used and each plot was replicated three times. Early, midseason, and late pickings were made, and in addition, the early picked plots were repicked at midseason. The same precautions, as mentioned above, were taken in regard to the picking, ginning, etc. These small lots of seed cotton were ginned on an 18-saw gin which had no cleaners. Three lint samples of each plot sample from each picking were taken while the cotton was being ginned.

All lint samples were numbered and submitted to two government licensed

[1]Contribution from the Department of Crops and Soils, Louisiana Agricultural Experiment Station, Baton Rouge, La. Submitted for publication Nov. 2, 1942.

[2]Agronomist, Louisiana Agricultural Experiment Station, and Superintendent, Northeast Louisiana Agricultural Experiment Station, respectively.

classers for grading. This arrangement provided for more than 100 classings of each variety each year and afforded a measure of the varietal difference in grade.

The following data on the varieties used may be of some value in interpreting the results:

Variety	Staple length, in.	Lint, %	Bolls seed cotton, per lb.
Delfos 531	1 1/8	33–34	75–85
Stoneville 2B	1 1/16	34–35	65–70
Deltapine	1 1/16	37–40	75–85
Miller	1	34–37	60–65
Dixie Triumph	1	34–36	75–85
Wilds	1 1/4	31–33	65–75

The main object of this study was to get a measure of the difference there is in the grade of different varieties of cotton when grown under the same conditions. No investigation was made of the influence of the varietal characters which may be responsible for differences in grade, but some suggestions are made as to the probable effect of certain characters.

RESULTS

The main results of the experiment are shown in Tables 1 to 8. An explanation of the meaning and value of the numbers in these tables is given in the footnote to Table 1. The tables show that there is a difference in the grade of varieties when grown under the same conditions and handled in the same way. The differences are not great but are consistent for different years at the same place and for the two places where experiments were conducted.

TABLE 1.—*Comparative mean grade values of cotton varieties grown at St. Joseph, La., 1939.**

Variety	First picking	Second picking	Third picking	Fourth picking	Mean for season
Delfos-531	12.86	13.11	17.16	17.96	15.27
Stoneville-2B	12.31	12.54	16.75	17.00	14.65
Deltapine	11.35	11.42	15.21	16.74	13.68
Mean for picking	12.17	12.36	16.37	17.23	——

*To facilitate obtaining averages, numbers were used for the various grades of cotton. Number 1 represents cotton a shade better than Middling Fair; No. 2 represents the regular grade of Middling Fair; No. 3, a shade lower than Middling Fair; No. 4, a degree better than Strict Good Middling; No. 5, Strict Good Middling; No. 6, a degree lower than Strict Good Middling, and so on, there being three unit numbers for each of the official standard cotton grades. In this system, 8 represents Good Middling; 11, Strict Middling; 14, Middling; 17, Strict Low Middling; and 20, Low Middling, etc. Since the grade value falls as the number increases, a fraction following a number subtracts from its value, as for instance 14.7 means a grade value 0.7 below 14, or Middling.

The test of significance shown in Table 9 is an analysis of data collected in one of the six experiments. Since similar methods were used in the other tests, their significance is probably about the same.

Delfos-531 was the lowest grading variety in the tests. This is a small bolled, 1 1/8-inch staple variety that is rather early and lets the cotton hang from its bolls. Stoneville-2B was next to the lowest

TABLE 2.—*Comparative mean grade values of cotton varieties grown at Baton Rouge, La., 1939.*

Variety	Picking* Sept. 5	Picking* Oct. 3	Early picking repicked Oct. 3	Picking* Nov. 5	Mean for season
Delfos-531	16.10	18.38	17.49	19.16	17.78
Stoneville-2B	14.83	16.66	17.94	18.98	17.10
Miller	14.55	16.88	16.77	18.94	16.78
Deltapine	14.16	16.38	16.71	18.77	16.50
Wilds	14.10	16.33	16.38	18.16	16.24
Dixie Triumph	13.55	15.94	16.16	18.16	15.95
Mean for picking	14.55	16.76	16.91	18.69	—

*These plots had not been picked previously.

TABLE 3.—*Comparative mean grade values of cotton varieties grown at St. Joseph, La., 1940.*

Variety	Picked Sept. 26			Picked Oct. 15			Picked Dec. 6			Mean value for season
	Av. value for press samples	Av. value for bale samples	Av. value for all samples	Av. value for press samples	Av. value for bale samples	Av. value for all samples	Av. value for press samples	Av. value for bale samples	Av. value for all samples	
Delfos-531	15.0	15.5	15.08	16.1	17.0	16.25	20.0	20.0	20.00	17.11
Stoneville-2B	14.1	16.0	14.42	14.1	14.0	14.08	19.9	20.0	19.92	16.13
Deltapine A.	14.1	15.5	14.33	14.0	14.0	14.00	19.2	18.5	19.08	15.80
Mean for picking			14.61			14.77			19.67	

TABLE 4.—*Comparative mean grade values of cotton varieties grown at Baton Rogue, La., 1940.*

Variety	Picked Sept. 5	Early picking—repicked Oct. 4	Picked Oct. 4 for first time	Picked Nov. 4 for first time	Mean value for season
Delfos-531	16.7	17.0	18.7	19.3	17.92
Stoneville-2B	16.0	17.0	18.7	19.3	17.75
Miller	14.7	17.0	17.0	19.0	16.92
Wilds	15.3	17.7	16.3	17.7	16.75
Dixie Triumph	14.7	17.0	17.0	18.3	16.75
Deltapine 11	15.3	16.3	17.7	17.0	16.57
Mean for picking	15.45	17.00	17.57	18.45	—

grading variety and Deltapine the highest. Stoneville is medium early and has a fair-sized boll, but the cotton protrudes from the boll considerably. Its staple is about $1\frac{1}{16}$ inches in length. Deltapine is a slightly later variety than either of the other two mentioned and

TABLE 5.—*Comparative mean grade values of cotton varieties grown at St. Joseph, La., 1941.*

Variety	Picked Sept. 8			Picked Oct. 6			Picked Nov. 6			Mean value for season
	Av. value for press samples	Av. value for bale samples	Av. value for all samples	Av. value for press samples	Av. value for bale samples	Av. value for all samples	Av. value for press samples	Av. value for bale samples	Av. value for all samples	
Delfos-531C....	16.7	15.5	16.1	17.8	17.5	17.6	19.8	19.0	19.4	17.70
Stoneville-2B...	16.0	14.0	15.0	17.0	18.5	17.7	19.0	18.5	18.7	17.13
Deltapine 12....	14.2	16.0	15.1	16.7	18.5	17.6	17.8	18.5	18.1	16.93
Mean for picking			15.40			17.63			18.73	

TABLE 6.—*Comparative mean grade values of cotton varieties grown at Baton Rouge, La., 1941.*

Variety	Picked Sept. 8*	Early picking—repicked Oct. 9	Picked Oct. 9 for first time	Picked Nov. 3 for first time	Mean value for season
Delfos-531C........	17.4	18.9	18.9	20.6	18.95
Stoneville-2B.......	17.0	18.5	18.3	19.6	18.35
Miller.............	16.9	17.3	17.8	19.2	17.80
Wilds.............	16.2	17.0	17.2	19.1	17.38
Dixie Triumph-366.	17.1	17.5	18.4	19.2	18.05
Deltapine 12.......	16.3	17.8	17.8	19.8	17.92
Mean for picking....	16.82	17.83	18.07	19.58	—

*Differences necessary for significance 19 to 1 ± 0.3424; 99 to 1 ± 0.4573.

TABLE 7.—*Three-year average of comparative grade values of cotton varieties grown at St. Joseph, La., 1939, 1940, and 1941.*

Variety	First picking	Second picking	Third picking	Fourth picking	Mean for varieties
Delfos-531.........	14.68	15.65	17.16	19.12	16.65
Stoneville-2B.......	13.91	14.77	16.75	18.54	15.99
Deltapine..........	13.59	14.34	15.21	17.94	15.27
Mean for pickings...	14.06	14.92	16.37	18.53	—

has a moderately small boll. It has a high lint percentage and on account of this there is a greater quantity of lint massed in the boll. This probably gives the lint some protection against the weather. Miller ranked third from the lowest among the varieties studied. Why this was the case is not apparent. It has the largest boll of the varieties studied and is only medium in respect to earliness. Its lint percentage is only fair. The average grade ranking of Wilds, Dixie Triumph, and Deltapine was so nearly the same that there is no significant difference. Wilds is a long staple variety that has a rather

TABLE 8.—*Three-year average of comparative grade values of cotton varieties grown at Baton Rouge, La., 1939, 1940, and 1941.*

Variety	Picked Sept. 5 to 8	Picked Oct. 3 to 9	Early picking—repicked Oct. 3 to 9	Picked Nov. 3 to 5	Mean for 3 years
Delfos-531	16.73	18.66	17.79	19.69	18.22
Stoneville-2B	15.94	17.88	17.81	19.29	17.73
Miller	15.38	17.23	17.02	19.05	17.17
Wilds	15.20	16.61	17.03	18.55	16.85
Deltapine	15.22	16.63	16.94	18.52	16.83
Dixie Triumph	15.05	17.15	16.88	18.55	16.91
Mean for pickings	15.59	17.36	17.25	18.94	—

TABLE 9.—*Test of significance of differences.**

Source of variation	D.F.	Sum of squares	Mean squares	F	Significance
Total	71	107.52	—	—	—
Replications	2	2.79	1.395	8.206	—
Varieties	5	14.50	2.900	17.59	Significant
Pickings	3	79.03	26.343	154.96	Highly significant
Variety × picking	15	3.38	0.225	1.32	—
Error	46	7.82	0.17	—	—

*Credit is due J. R. Cotton and E. L. LeClerg for making the statistical analysis.

low lint percentage and not very large boll, considering the weight of seed cotton, but there is a large and heavy bur which perhaps gives the cotton some protection. Dixie Triumph is a medium late, healthy, vigorous-growing variety that is more free of disease than most other varieties. This probably influences the grade to some extent. Early varieties of determinate growth tend to mature and shed leaves early in the season. Fragments of some of these dead leaves fall on the open cotton bolls and affect the grade more or less. In Arizona and California, there is some objection to Ambassador (Stoneville 4) due to its hairyness. It is the belief of some of the growers that hairs from stem and leaves fall on the exposed lint in the open bolls and lower its grade.

The average difference between the best and lowest grading varieties at St. Joseph for the 3-year period was 1.38, which was less than ½ grade. At Baton Rouge for the same period of time, the difference was 1.39, a value almost exactly the same as at St. Joseph. Similar values prevailed each year of the 3-year period.

Based on 432 classings, the pressbox samples gave a slightly better grade than the bale samples, the difference being 0.28. This is only about 1/10 grade, but it is of some value in that it shows that in the hands of experienced classers, pressbox samples are valued as highly as bale samples. Some growers have been of the opinion that it is necessary to have a bale sample to get a true classing.

The average seasonal deterioration in grade at Baton Rouge between the first picking in September and the last picking in Novem-

ber was 3.35, or slightly more than 1 grade. There was a very similar deterioration in grade each year during the period. The average seasonal deterioration at St. Joseph was 4.47, or about 1½ grades. This lower average at St. Joseph was due largely to the fact that in 1940 the last picking was not made until in December. This picking showed a deterioration of almost 2 grades when compared with the first picking in September. Other years the seasonal dropping off in grade was about the same as at Baton Rouge.

In studies made by Smith and McNamara[3] in Mississippi, a difference of approximately ½ grade between $1\frac{1}{16}$ to 1 3/32 and 1 5/32 to $1\frac{3}{16}$ inch cotton was noted. The longer cotton gave a slightly lower grade consistently. Their work was based on several thousand bales of cotton grown in the Mississippi Delta and handled and classed by the Staple Cotton Association, Greenwood, Miss.

GENERAL DISCUSSION

It is a rather difficult matter to place monetary values on the grade differences of the various cotton varieties, since the value is affected by so many different factors, namely, (a) market value of cotton, (b) differences in relative value of different staple lengths at a particular time, (c) grade differences of the long staple cottons affect their value several times as much as similar grade differences of short staple cottons, and (d) relative values vary at different times depending on market demands. There is also greater value difference between some grades than others even if the cotton is of the same staple length. Considering all of these influencing factors, and there are others, it is a difficult matter to make a general statement in regard to the money values of grade differences.

In the present (September 11, 1942) Memphis, Tenn., market, Middling 15/16 -inch cotton is worth 18.55 cents per pound. One-inch Middling grade cotton is listed at 18.85 cents per pound; 1-inch Strict Middling at 19.10 cents; and 1-inch Strict Low Middling at 17.60 cents. This is a grade value difference of 0.25 cent per pound in one case and 1.25 cents in the other. In the same market on the same day, 1⅛-inch Middling cotton was quoted at 22.80 cents per pound; 1⅛-inch Strict Middling at 23.80; and 1⅛-inch Strict Low Middling at 20.30. This was a value difference, for 1 grade difference, of 1.00 cent a pound in one case and of 2.50 cents in the other. The quotation for 1¼-inch Middling cotton in that market on the same day was 28.05 cents per pound; for Strict Middling 1¼ inch, 29.55 cents; and for Strict Low Middling 1¼ inch, 24.80 cents. Here there is a grade value difference of 1.50 cents in one case and 3.25 cents in the other.

From the quotations given above, it may be seen that the money values attached to different grades of cotton vary greatly and that the differences are very small for the short staple cottons. If the grade difference between varieties is only ½ grade, as was shown to be the case in this study, the monetary difference in value, if based on grade

[3]McNamara, H. C., and Smith, C. C. Shall we grow long cotton or short? The Staple Cotton Review, 19: No. 11. 1941.

alone, cannot be great, especially if the cotton is a short staple cotton. One half grade difference will not be equivalent to a difference of more than a small fraction of a cent per pound. With the longer staple cottons, ½ grade difference may make a difference in value of 1 or 2 cents a pound in some cases.

The main reduction in cotton grades results from exposure to weather during the period the open bolls are in the field. Some further reduction may be due to carelessness of the cotton pickers and to improper ginning. These studies showed that under normal Louisiana conditions there is a weather damage deterioration of about 1 grade between September 1 and November 1. Between September and December there was a drop of 2 grades at St. Joseph.

The cotton at St. Joseph, on the whole, gave a somewhat better grade than cotton from Baton Rouge, the difference being from about ½ to 1 grade. There were two variable factors affecting this, one, the difference in weather of the two places, and, the other, the difference in the way the cotton was ginned. At St. Joseph, cotton cleaners were used when ginning. Both of these factors evidently had some influence, but with the setup used in the experiment it was not possible to get an accurate measure of each.

SUMMARY

1. Lack of data on the subject prompted a study of the influence of varietal differences on the grade of cotton.

2. Six of the leading cotton varieties grown in Louisiana were studied. Three of them were grown in the delta area of northeastern Louisiana where conditions are favorable for growing cotton. All six varieties were grown at Baton Rouge in southern Louisiana where conditions are not favorable.

3. The varieties at each place were handled the same in respect to culture, harvesting, and ginning.

4. The tests showed that there is about ½ grade difference between the best and poorest grading varieties.

5. The grade appeared to be affected to some extent by the lint percentage of the cotton, the period of boll opening, the healthfulness of the plants, and size of the boll burs.

6. As was to be expected, lower grades were obtained from later pickings. The seasonal deterioration was from 1 to nearly 2 grades.

7. Pressbox samples were given slightly higher grades than bale samples.

NOTE

A SINGLE-DISC SCARIFIER FOR SMALL LOTS OF SEED

THE single disc scarifier shown in Fig. 1 was constructed at the Soil Conservation Service Nursery, Rock Hill, S. C., for test scarifications of kudzu seed in the spring of 1942. It has been used since for scarifying small lots of other kinds of seed.

It consists of a commercial mandrel and locally constructed plywood disc and hood. The disc is 12 inches in diameter, and has fine-grain emery paper glued on both sides. The hood has an inside diameter of 12¾ inches. It has an intake funnel above and a discharge funnel below, both provided with sliding metal gates flush with the hood surface to confine seed during scarification. The hood is held in place by metal straps firmly attached to a work bench or table.

FIG. 1.—A single-disc seed scarifier for small lots of seed.

Power is furnished by a small electric motor. The disc should clear the floor of the hood by ¼ to ⅜ inch for small seed.—PAUL TABOR, *Soil Conservation Service, Spartanburg, S. C.*

AGRONOMIC AFFAIRS

CROP PRODUCTION SPECIALISTS WANTED

PERSONS with a practical knowledge of the production of rubber and oil-producing crops and other tropical plants, including the procurement of wild rubber, are being sought by the U. S. Civil Service Commission. For some positions persons are desired who have had education with major study in agronomy, horticulture, plant breeding, forestry, or other courses related to plant production, in addition to the required experience.

Salaries are $2,600 to $8,000 a year. While some positions will be filled in the United States, a majority of them will be filled outside its continental limits, principally in South and Central America. Additional compensation will be paid for foreign duty.

Persons appointed will do work in connection with the establishment and operation of research stations or plantations growing rubber or oil-producing plants. Plantations, for the most part, will be situated in remote and primitive areas. The duties will involve making surveys of the country to determine selection of proper sites, soils, and other essential factors.

The three options are rubber plants, oil-producing plants, and other tropical plants. Experience in any of the three is acceptable, which must have been acquired in their growing, or in research, extension, or closely allied work. In general, at least 6 months of such experience must be shown for the assistant grade, at $2,600 a year. The minimum requirements for the higher grades are proportionately higher.

Qualified persons are urged to file applications immediately with the U. S. Civil Service Commission, Washington, D. C. There are no age limits, and no written examination will be given. Applications and complete information may be obtained at first- and second-class postoffices, from civil service regional offices, and from the U. S. Civil Service Commission, Washington, D. C.

NEWS ITEMS

ACCORDING TO SCIENCE, Professor D. B. Johnstone-Wallace has been granted a year's leave of absence from Cornell University to enable him to accept an invitation of the British Ministry of Agriculture to become head of the agricultural department of the National Institute for Research in Agricultural Engineering, which has been moved from the University of Oxford to York. His work will deal with the development of mechanical processes to increase food production, including grass silage for livestock, dehydration of grasses and legumes, plowing up of grassland for other crops, and establishment of new pastures.

Royse P. Murphy, Associate Agronomist at the Montana State College, has been granted a leave of absence for the duration of the war in order that he might serve as Geneticist on the Guayule Research Project at Salinas, Calif.

—A—

M. A. Sprague, formerly of the Department of Agronomy, University of Arkansas, is now an ensign, USNR, in attendance at the U. S. Naval Reserve Midshipmen's School at the University of Notre Dame.

—A—

Omer J. Kelley, formerly of the Ohio Agricultural Experiment Station at Wooster, is now Soils Technologist for the Rubber Plant Investigations at Salinas, Calif.

—A—

Doctor Harald E. Hammar of the Division of Soil Fertility Investigations of the Bureau of Plant Industry, U. S. Dept. of Agriculture, has been transferred from soil fertility investigations and chemical work on pecans at Shreveport, La., to work on peanuts and pecans at Albany, Ga., as being more vital to the war effort.

—A—

C. S. Coleman, Assistant Agronomist assigned to soil survey work in Virginia, has been inducted into the armed services.

—A—

Vegetable seed which will produce more than 1,000,000 tons of food is being shipped to the Soviet Union by Russian War Relief, according to Francis C. Stokes, chairman of the Vegetable Seed Committee of that agency. About half of the seed, which weighed more than 950,000 pounds, was contributed by 150 American firms and the remainder purchased from the American seed trade with funds raised for that purpose by Russian War Relief.

—A—

A citation of Fred H. Bateman of Gremloch, N. J., for distinguished service to New Jersey agriculture was made recently by the New Jersey Department of Agriculture in special recognition of his contributions as an inventor and developer of farm machinery. "New Jersey farmers are indebted to you for many of the more recent improvements in labor-saving, mechanized implements which have been made available as a result of your inventive genius, perseverance, practical skill, and loyal devotion. Your ability to adopt promptly equipment to new practices and methods has been recognized throughout the nation as well as in your home state", reads the citation.

—A—

Delmar S. Fink, formerly with the Maine Agricultural Experiment Station, has been appointed Assistant Professor of Agronomy at Cornell University.

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CHLOROTIC DIEBACK OF FLAX GROWN ON CALCAREOUS SOILS[1]

H. H. FLOR[2]

LOCAL areas bearing chlorotic plants are a conspicuous feature of many flax fields in the Red River Valley of North Dakota and Minnesota during the early summer. Some of these are water-logged spots in poorly drained fields where the plants recover when conditions favorable to growth are restored, unless too severely affected. Another type of flax chlorosis, caused by soil conditions, is the subject of these investigations. Although chlorosis is usually the most conspicuous symptom, the term "chlorotic dieback" is more descriptive of the abnormal condition.

SOIL CONDITIONS

The areas producing plants affected with chlorotic dieback vary in extent from a few square yards to several acres. Although irregular in outline, these areas are stable from year to year. The soil surface in affected areas is not visibly depressed. The unproductive areas occur on the shoulder and slope adjacent to swales or sloughs (Fig. 1), or in level fields. The affected spots are characterized by shallow greyish surface soils in contrast to the deeper black surface soils of productive areas.

The unproductive areas of fields producing "chlorotic dieback" are commonly designated "alkali spots". Although they are usually lighter in color than adjacent productive areas, there was no indication of excessive alkali accumulation in the unproductive areas of the two fields studied in these investigations. Hide (4)[3] found that certain unproductive areas near Crookston, Minn., were irregular in outline from year to year and that the unproductivity of these areas was corrected by supplying adequate moisture. Consequently, these areas undoubtedly were different from those producing chlorotic dieback of flax described in this paper. The latter differ also from the slick spots (2) that occur in certain Nebraska soils in that they are not

[1]Cooperative investigations between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the North Dakota Agricultural Experiment Station. Received for publication October 29, 1942.

[2]Pathologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3]Figures in parenthesis refer to "Literature Cited", p. 269.

high in sodium nor noticeably deflocculated. The alkaline condition of the soil of the Nebraska slick spots and the numerous highly calcareous areas throughout the West appear to render phosphorus and iron insoluble and to cause chlorosis in various plants. Hopper and Walster (5) found that surface soils in Cass County, N. Dak., usually were relatively low and the subsoils high in calcium. However, different fields of the same soil type showed wide variations in the percentage of calcium in surface, subsurface, and subsoil horizons.

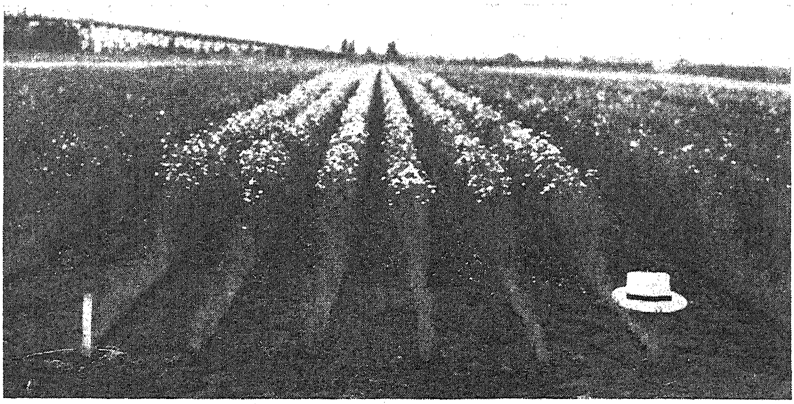

FIG. 1.—Flax severely affected with chlorotic dieback growing on the border of a swale in Fargo clay soil.

Schilling (9) considers flax a definitely "lime sensitive" plant and cites the pot experiments of a number of investigators showing that applications of lime exert a very injurious effect on the growth and development of flax, especially in the young stages. Scholz (10) in pot experiments in quartz sand found that calcium carbonate caused severe chlorosis when iron was deficient. However, this same investigator (11) after extensive tests concluded that under field conditions flax is not "lime sensitive". In later investigations Scholz (12) concluded that the injurious effect of lime was due to the action of calcium in hindering the absorption of phosphate and iron by rendering them insoluble.

SYMPTOMS OF CHLOROTIC DIEBACK IN FLAX

Flax appears to be affected more adversely by the unproductive soil condition than other commonly grown crops. Grass crops appear to tolerate the abnormal soil condition and it is probable that portions of fields containing numerous unproductive areas have been retired from cultivation and devoted to permanent pasture or meadow.

Flaxseed sown in unproductive areas germinates normally. Under cool, wet conditions the cotyledons may show some chlorosis, but usually cotyledonary chlorosis is much less severe than that of the leaves on the primary stem. The leaves formed during cool, wet weather are severely chlorotic and if these conditions persist for

several days the terminal bud is killed and the primary stem dies back to the cotyledonary node. In severe cases the plant is killed, but usually lateral branches are sent out at the cotyledonary node. If unfavorable weather continues, some or all of the new laterals may die and additional ones may be sent out. With the advent of warm weather normal foliage is produced and by midsummer many of the plants in the affected area recover and produce some seed. If the soil is dry during a period of cool weather, there is little chlorosis, but the cotyledons develop a greenish-bronze cast and the entire plant has a pinched appearance. The stunted leaves develop necrotic flecks which enlarge and lead to premature shedding. Leaves formed during a warm period that occurs between two cool, cloudy periods may appear normal in size and color, while those formed at the base and near the top of the stem during the cool periods are stunted, develop necrotic lesions, and are usually more or less chlorotic. The functional period of leaves on plants growing in the unproductive areas is usually shorter than that of leaves on plants growing in adjacent productive soil.

MATERIAL AND METHODS

Soil from two sources was used in these investigations, a Fargo clay from the experiment station fields at Fargo, Cass County, and a Bearden silt loam from Buxton, Traill County, N. Dak. Tests were made in the greenhouse to determine the effect on the growth of Bison flax of leaching, steaming, and the addition of trace elements, soil amendments, and fertilizers to unproductive soil. The response to soil temperature and to water-holding capacities in both productive and unproductive soil was determined by means of Wisconsin soil temperature tanks.

The saturation point (water-holding capacity) of the different horizons of the unproductive Fargo clay soil varied from 86 to 94% of the dry weight and that of the Bearden silt loam ranged from 65 to 70%.

EXPERIMENTAL RESULTS

CHEMICAL TESTS

Soil samples from productive and unproductive areas at Fargo were tested for pH, total soluble salts, presence of sodium, and the amount of calcium carbonate. No determinations of magnesium were made and the carbonate determinations did not distinguish between calcium and magnesium. The results of these tests are given in Table 1.

The chemical tests of the soils indicated that there was little difference in pH between the productive and unproductive soils and that black alkali (sodium carbonate) was not present in appreciable quantities in the unproductive areas. The concentration of 2,253 p.p.m. of soluble salts in the 0- to 3-inch horizon of unproductive soil approached the toxic level. However, the soil was dry when gathered and the salts may have been concentrated near the surface. The salt concentration in the 4- to 6-inch horizon of unproductive soil was about the same as that in the 0- to 6-inch horizon of productive soil, while the salt concentration of the 7- to 9-inch and 10- to 12-inch unproductive soil horizons were actually less than that of the 7- to 12-inch productive soil horizon. The calcium carbonate content

TABLE 1.—*Tests of productive and unproductive Fargo clay soil.**

Soil	Horizon	pH	Soluble salt, p.p.m.	Calcium	Sodium	Calcium carbonate equivalent of CO_2
Productive....	0-to 6-inch	7.4	870	Very low (400)	None	0.7†
Productive....	7-to 12-inch	7.6	1,300	High (3,000)	None	—
Unproductive..	0-to 3-inch	7.2	2,253	High (3,000)	None	1.3
Unproductive..	4-to 6-inch	7.6	960	Moderately high (2,000)	None	2.7
Unproductive..	7-to 9-inch	7.8	975	High (3,000)	None	7.0
Unproductive..	10-to 12-inch	7.6	1,038	High (3,000)	None	11.5
Unproductive..	13-to 18-inch	7.8	1,062	High (3,000)	Trace	14.1

*Determinations of pH, soluble salts, calcium, and sodium by E. A. Helgeson, Department of Botany, using Morgan's (8) universal soil-testing methods, and test for calcium carbonate by Arvid J. Cline, Department of Soils, North Dakota Agricultural Experiment Station.
†Average for 0- to 7-inch horizon of Fargo clay in Cass County as reported by Hopper and Walster (5).

of the 0- to 3-inch and 4- to 6-inch unproductive soil horizons was not excessive. However, the calcium content was much higher than that of the corresponding productive soil horizon. The calcium carbonate content in the lower horizons approximated the analyses reported by Hopper and Walster (5) in their studies on the chemical composition of Cass County Fargo clay soils.

ADDITION OF CHEMICALS

A limited series of greenhouse tests were conducted to determine what effect additions of fertilizers, soil amendments, and trace elements to the unproductive soil would have on growth of flax and the appearance of disease symptoms. The following chemicals were added to 0- to 6-inch and 7- to 12-inch horizons of unproductive Fargo clay soil:

Chemical	Rate of application, pounds per acre
1. Sodium nitrate	400
2. Sodium dihydrogen phosphate	840
3. Potassium chloride	120
4. Calcium sulfate (gypsum)	2,000
5. Colloidal sulfur	2,000
6. Boric acid	20
7. Copper sulfate	30
8. Manganese sulfate	150
9. Zinc sulfate	100
10. Ferric chloride	30
11. Ferric chloride	300

In these tests the flax was grown in soil maintained at 15° C and 50% of its water-holding capacity. Sodium dihydrogen phosphate and, to a lesser extent, sodium nitrate were the only chemicals tested that improved the growth of the plants and gave indications of

correcting the unproductive condition of the soil. Colloidal sulfur and ferric chloride gave no response, which might indicate that the chlorotic dieback is not due largely to iron deficiency.

SOIL TEMPERATURE, MOISTURE, AND LEACHING (EXPERIMENT 1)

Preliminary tests were conducted to determine the effect of variations in soil temperature and moisture and of leaching on the toxic properties of Fargo clay soil from an unproductive area as indicated by the growth of Bison flax. Lots of soil were taken from an unproductive area at depths of 0 to 3 inches, 4 to 6 inches, 7 to 9 inches, 10 to 12 inches, 13 to 18 inches, and 0 to 6 inches and from 0 to 6 inches of a productive area. Half the unproductive soil of the 0- to 6-inch horizon was leached with several times its volume of water. Temperatures of 15° and 20° C and moisture contents of 30, 40, and 50% of the soil water-holding capacity were used in these tests. This series of soil temperature tanks accommodated 48 cans so that only 1 can of each variable was tested. Bison flax was sown at the rate of 12 seeds per can and the average height of the plants of each variable was measured at 24, 70, and 110 days after sowing. Data for the 110-day readings are shown in Table 2. Differences were small at the 24-day period, but the relative heights at 70 days corresponded closely with those at 110 days.

TABLE 2.—*Effect of soil moisture and temperature on the height of Bison flax grown in different soil horizons.*

Soil horizon, inches	Experiment 1						Experiment 2					
	Plant height (inches) at 110 days in soil at						Plant height (inches) at 70 days in soil at					
	30% water-holding capacity		40% water-holding capacity		50% water-holding capacity		30% water-holding capacity		50% water-holding capacity			
	15°C	20°C	15°C	20°C	15°C	20°C	12°C	25°C	12°C	15°C	20°C	25°C
	Unproductive Soil											
0 to 3	12	10	24	34	25	30	11	18	15	18	21	25
4 to 6	18	16	26	40	27	28	12	18	12	16	21	25
7 to 9	12	16	24	28	20	20	8	16	9	13	19	23
10 to 12	7	11	8	18	6	17	5	11	6	8	12	20
13 to 18	7	10	6	14	7	13	4	10	6	8	10	17
0 to 6	17	17	30	30	20	27	—	—	—	—	—	—
	Unproductive Soil, Leached											
0 to 6	20	18	31	34	26	41	—	—	—	—	—	—
	Productive Soil											
0 to 6	20	16	34	36	43	49	20	22	25	28	31	30

Disease symptoms similar to those of flax plants growing on unproductive areas in the field were obtained in these greenhouse tests. The plants growing in the soil from the deeper horizons and at the lower temperature were most severely affected. There was insufficient moisture in the soil kept at 30% of its water-holding capacity to support normal growth, but flax growing in soil from the unproductive area at this moisture content, particularly that from the lower horizons, resembled that grown in the field under dry conditions. The cotyledons became bronzed, the plants, although stunted, had a dark green color and the leaves developed necrotic flecks and spots. In soil maintained at a temperature of 15° C, the terminal buds on many plants died and secondary branches arose from the cotyledonary node or from the primary stem below the dead bud. Plants grown in the wetter unproductive low horizon soils developed considerable chlorosis even when grown in soil kept at 20° C, but dieback of the primary stem was less pronounced. There was little difference in the growth of plants in the unproductive soils kept at 40 and 50% of their water-holding capacities, but plants grown in productive soil at 50% of its water-holding capacity were uniformly larger than those grown in the soil kept at 40%. This preliminary test indicated that severe symptoms of the disease were associated with low soil temperature and that chlorosis, as distinguished from stunting and necrosis, was dependent upon adequate soil moisture.

There was little difference in the appearance of plants growing in the leached and unleached unproductive soil. Plants growing in leached soil had a little better color and usually were a little larger than those growing in unleached soil under similar conditions, but the differences were small and too irregular to indicate that leaching had removed any deleterious constituent.

Additional temperatures were used in the second experiment (Table 2).

In the unproductive soils each increase in soil temperature throughout the range of 12° to 25° C resulted in a consistent increase in height of plants (Fig. 2, cans 5 to 8). The injurious effect of low soil temperatures as well as the beneficial effect of high soil temperatures was most pronounced in unproductive soils from the deeper horizons. Differences in height of plants grown in productive soil at 12°, 15°, 20°, and 25° C were relatively small (Fig 2, cans 1 to 4), plants grown in soil maintained at 20° C actually being a little taller than those grown in soil at 25° C.

EFFECT OF FERTILIZERS

Fargo Clay soil.—Lots of soil from an unproductive area at Fargo were dug in 3-inch horizons to a depth of 9 inches. Cans were filled with these soil lots duplicating the horizons in the field. Nitrogen as sodium nitrate, phosphate as monobasic sodium phosphate, and potash as potassium chloride were added to the surface layer of soil in the cans in amounts equivalent to the application at the rate of 800 pounds per acre of variations of a 4–12–4 fertilizer as indicated in Table 3. The fertilizer was also added to cans containing surface soil from a productive area. The moisture content of the soil was

maintained at 50% of its water-holding capacity in this test. Two cans of each variable of unproductive and one of productive soil were used. Most of the cans contained 10 to 12 plants.

The data obtained in this test (Table 3), although somewhat variable, show that flax plants grown at a temperature of 12° C in soil to which phosphate had been added were consistently larger than

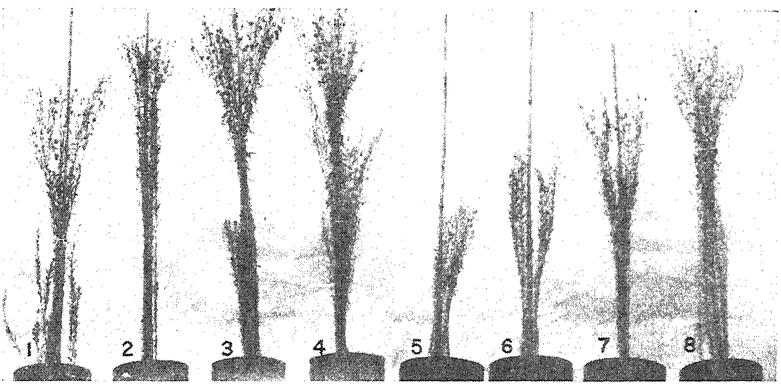

FIG. 2.—Bison flax grown in soil maintained at approximately 50% of its water-holding capacity. Cans 1 to 4 in productive soil at 12°, 15°, 20°, and 25° C respectively; and cans 5 to 8 in the 4- to 6-inch horizon of unproductive soil at 12°, 15°, 20°, and 25° C, respectively.

those grown without added phosphate. However, the addition of phosphate did not wholly correct the soil trouble as is shown by the much greater green weights obtained in the productive soil. Phosphate applications were likewise beneficial to the productive soil. The favorable effect of phosphate applications on the growth of flax was less at 25° C than at 12° C. This is in agreement with field observations that plants suffering from chlorotic dieback tend to recover with the advent of warm weather. In this severely affected unproductive Fargo clay soil, raising the soil temperature was more beneficial than adding fertilizers but neither corrected the abnormal condition.

Bearden silt loam.—Bison flax growing in certain areas in a field of Bearden silt loam near Buxton, N. Dak., was similar in appearance with that of flax growing in the unproductive soil at Fargo. The effect of adding fertilizers to 0– to 3–inch, 4– to 6–inch, 7– to 9–inch, and 10– to 12–inch soil horizons from an unproductive area of this field as indicated by the growth of Bison flax was studied in the greenhouse. In this experiment flax was grown in No. 3 cans that had been coated with aluminum paint. Nitrogen was supplied as ammonium sulfate, phosphate as superphosphate, and potash as potassium chloride. These chemicals were mixed with the surface inch of each horizon of unproductive soil in amounts equivalent to 800 and 1,600 pounds per acre of 4–0–0, 0–12–0, 4–12–0, and 4–12–4 analysis. In addition to the fertilizer tests the effect on the growth of flax of steaming the unproductive soil for 2 hours at 15 pounds pressure was determined.

TABLE 3.—*Effect of fertilizers on the growth of Bison flax in unproductive and productive Fargo clay soil.*

Fertilizer analysis, N-P-K	Flax grown in unproductive soil				Flax grown in productive soil	
	Height of plants (inches) at		Total green weight (grams) per can at		Height of plants (inches) at 12°C	Total green weight (grams) per can at 12°C
	12°C	25°C	12°C	25°C		
4-0-0	26	41	8	34	45	66
0-12-0	34	39	17	35	46	83
0-0-4	29	—	11	—	47	70
4-12-0	32	39	15	34	47	85
4-0-4	26	—	8	—	48	83
0-12-4	29	—	13	—	48	80
4-12-4	30	—	14	—	48	102
0-0-0	29	38	10	30	48	72

During this test the soil was kept at 60% of its water-holding capacity and as cool as was possible with tap water, the soil temperature varying from 7° to 10° C. The soil cans receiving the 800-pound fertilizer applications were resown at the termination of the first experiment and kept at a temperature of about 25° C. The results of this test are given in Table 4.

TABLE 4.—*The effect of fertilizers on growth of Bison flax in unproductive Bearden silt loam soil maintained at 60% of its water-holding capacity.*

Fertilizer analysis or soil treatment, N-P-K	Rate of application per acre, pounds	Total green weight in grams of plants per can grown at a soil temperature of							
		7° to 10° C (first crop)				25° C (second crop)			
		Soil horizon				Soil horizon			
		0- to 3-inch	4- to 6-inch	7- to 9-inch	10- to 12-inch	0- to 3-inch	4- to 6-inch	7- to 9-inch	10- to 12-inch
4-0-0	800	5.1	3.4	1.0	1.0	12.5	13.0	7.0	1.5
0-12-0	800	10.5	11.3	5.6	3.5	9.0	6.5	4.0	3.5
4-12-0	800	12.2	11.8	6.2	1.7	8.5	8.5	6.0	6.0
4-12-4	800	13.2	12.0	5.6	1.1	8.0	8.0	5.5	5.5
Untreated	None	3.3	3.3	1.0	0.9	8.5	9.0	6.0	3.5
Steamed	None	3.7	2.9	1.1	0.9	—	—	—	—
4-0-0	1,600	5.8	3.3	0.9	0.9	—	—	—	—
0-12-0	1,600	12.4	12.2	8.4	5.5	—	—	—	—
4-12-0	1,600	15.4	13.2	9.0	3.4	—	—	—	—
4-12-4	1,600	16.1	14.2	10.4	1.2	—	—	—	—
Productive soil	None	15.3	—	—	—	—	—	—	—

The size and vigor of flax plants growing in the unproductive Bearden silt loam at low soil temperatures and with adequate moisture decreased progressively with each increase in depth of soil in which they were grown. The unproductive Bearden silt loam responded more favorably to phosphate applications than did the Fargo clay. Bison flax plants growing in soil from the 0- to 3-inch and 4- to 6-inch horizons receiving superphosphate at the rates of 223 and 445 pounds per acre were almost as large and vigorous as those growing in productive soil (Fig. 3), and at the end of 50 days had green weights

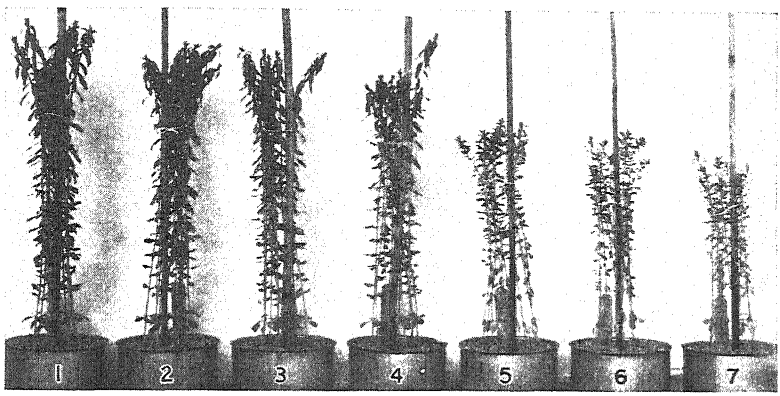

FIG. 3.—Response of Bison flax growing in unproductive Bearden silt loam soil to applications of fertilizer at the rate of 800 pounds per acre. Soil kept at 7° to 10° C and 60% of its water-holding capacity. Can 1 (check), surface horizon of productive soil. Cans 2 to 7, the 4- to 6-inch horizon of unproductive soil treated as follows: can 2, 4–12–4 fertilizer; can 3, 4–12–0 fertilizer; can 4, 0–12–0 fertilizer; can 5, 4–0–0 fertilizer; can 6, steamed; and can 7, untreated.

of three to more than four times those of flax growing in the unfertilized soils. The addition of nitrogen in the form of ammonium sulfate at the rates of 150 and 300 pounds per acre was slightly beneficial to plants growing in the 0- to 3-inch horizon but was virtually without effect in soil from deeper horizons. Supplementing phosphate with nitrogen and nitrogen and potash fertilizers were consistently beneficial in the unproductive soil from the 0- to 3- and 4- to 6-inch horizons, were either beneficial or neutral in effect in the soil from the 7- to 9-inch horizon, and were deleterious in the soil from the 10- to 12-inch horizon. Steaming had little effect on the productiveness of the soil as, in each instance, the weight of flax plants grown in the steamed soil approximated that of plants growing in the corresponding untreated soil.

In this test the addition of phosphate to the 0- to 3-inch and 4- to 6-inch horizons of unproductive Bearden silt loam soil virtually corrected the unproductive condition. Flax grown for 50 days in the 0- to 3-inch horizon of unproductive soil that had received applications of 4–12–0 and 4–12–4 fertilizers at the rate of 1,600 pounds per acre was as vigorous and weighed slightly more than flax grown under the same conditions in the 0- to 6-inch horizon of productive soil.

The test in which flax was resown in soil that had received 800-pound fertilizer applications and produced a crop at a soil temperature of 7° to 10° C indicated that at a soil temperature of 25° C there was virtually no residual effect of the phosphate fertilizer. There was a residual response in soils that had received nitrogen but had failed to respond in the first test. As in the tests with unproductive Fargo clay soil, the deleterious effect of the unproductive Bearden silt loam was much less pronounced at the higher soil temperature.

DISCUSSION

Breazeale and McGeorge (1) found that plants absorb nitrate and phosphate ions with difficulty at a pH above 7.6, approximately the pH of the Fargo clay soil. Because of its effect on pH they consider carbon dioxide the most important single factor in the fertility of alkaline calcareous soils. They point out that under conditions of good aeration and drainage carbon dioxide is respired by plant roots and, in an alkaline soil, this lowers the pH to the range permitting absorption of nutrients. The decomposition of organic matter also greatly increases the carbon dioxide supply in the soil likewise reducing the pH.

McGeorge (6) found that the pH of a calcareous soil varied with the soil water ratio of dilution and increased with dilution. He reported (7) little difference in pH values at different moisture contents below the water-holding capacity of the soil, but Haas (3) stated that at moisture percentages at or above their moisture equivalents calcareous soils may be quite alkaline while at low moisture contents they may be quite acid. In the studies on chlorotic dieback the moisture content of the soil appeared to have little effect on the absorption of the critical nutrients as flax plants growing in soils varying in moisture content from slightly above the wilting point to decidedly waterlogged were stunted and developed necrotic lesions. However, the chlorotic phase of the disease appeared to be associated with adequate or excessive moisture.

The local soil areas on which chlorotic dieback of flax occurs appear to have suffered more or less erosion, resulting in dissection of the landscape along certain depressions, so that the highly calcareous subsoil has become exposed. Consequently, the seedling flax plant is dependent for its supply of minerals, other than those contained in the seed, largely upon the nutrients absorbed from this highly calcareous subsoil. A number of factors may be involved in the midsummer recovery of flax plants suffering from chlorotic dieback. The work of Breazeale and McGeorge (1) suggests that as the soil becomes warmer increased biological activities of soil organisms and the respiration of plant roots release increased quantities of carbon dioxide and organic acids which lower the pH of the soil, making phosphates more soluble. In the Red River Valley the moisture content of field soils usually decreases as the season advances and as Haas (3) points out the pH of some soils is lowered by decrease in moisture content. Also, it is possible that some of the phosphates, with which most Red River Valley soils are well supplied (5), may be less insoluble in the warmer soil solutions. The disproportionate effect of increase in soil

temperature on flax growing in unproductive soil as compared with flax growing in productive soil, and the diminution in the beneficial effects of phosphate applications to unproductive soils with rise in soil temperature, suggests that native phosphates become increasingly available as the soil temperature is raised. The development of branch roots in the more fertile topsoil also contribute to the recovery of affected plants when warm weather arrives.

Unproductive areas vary greatly in the severity of adverse effects on flax. The power of these soils to fix phosphates was not determined, but the limited improvement following phosphate application to the Fargo clay soil and the lack of response in the second crop grown on the Beardon silt loam indicate that application of phosphate may not be economically feasible. Plot tests on individual fields are advisable before applying fertilizers to control chlorotic dieback. In the meantime, fields containing unproductive areas should be devoted to cereals and grasses which are more tolerant than flax to the unfavorable soil condition.

SUMMARY

Chlorotic dieback, a nonparasitic disease of flax, is associated with certain unproductive soil areas in the Red River Valley of North Dakota.

When flax is grown experimentally in soils representing successively deeper soil layers, the disease is least severe in surface soil and increases in severity for each successively lower horizon.

Chemical tests of soil from an unproductive area, as well as the growth of flax in such soils that had been steamed, or leached, failed to indicate the presence of a toxic substance.

Flax grown in unproductive soils to which mineral amendments had been added responded favorably to the addition of phosphate.

The chlorotic phase of the disease was more pronounced in the wetter soils, but plants grown in both wet and dry soils were stunted and showed symptoms of leaf necrosis and stem dieback.

The disease symptoms were most severe at low soil temperatures and showed progressive diminution in intensity with rise in soil temperature ranging from 12° to 25° C. Flax growing in unproductive soil responded more favorably to increases in soil temperature than did that growing in productive soil.

Applications of phosphate to the Bearden silt loam corrected its unproductiveness and the chlorotic dieback symptoms. Similar applications to the Fargo clay soil were only partially corrective. It is suggested that the flax trouble at low soil temperatures is caused, at least in part, by deficiency or unavailability of essential minerals, especially phosphate, in the highly calcareous alkaline soil.

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THE RESPONSE OF VETCH AND SOYBEANS TO STRAINS OF NODULE BACTERIA[1]

W. B. ANDREWS AND CHAS. F. BRISCOE[2]

THE classification of leguminous plants into cross-inoculation groups facilitates the use of efficient cultures by farmers. Cross-inoculation groups have acquired the meaning probably by most agricultural workers and farmers that efficient nitrogen fixation is obtained when all plants of a cross-inoculation group are inoculated with a culture for the group. The ones who put the information into practice are interested primarily in efficient nitrogen fixation. From the standpoint of putting the information gained to the best use, it appears that plants in a cross-inoculation group should be inoculated and efficient nitrogen fixation should be obtained by a given culture, rather than the mere production of nodules without regard to the efficiency of nitrogen fixation.

If soil bacteriologists would accept efficiency in nitrogen fixation as a criteria for cross-inoculation groups, divisions of cross-inoculation groups based on the efficiency of nodule bacteria would be in order.

Producers of commercial inoculants are placing cultures on the market so labeled that divisions of cross-inoculation groups are indicated. Insofar as these inoculants are specific for the plants in question, the commercial companies are rendering a better service than supplying an over-all culture for the cross-inoculation group. The use of several strains of nodule bacteria in a culture by producers of commercial inoculants helps to overcome variations in the efficiency of strains of nodule bacteria on species of plants within cross-inoculation groups.

With the isolation of more strains of nodule bacteria specific to plants occurring in cross-inoculation groups, it appears that the use of the designated cross-inoculation groups by agricultural workers will decrease. However, it is suggested that the division of the present cross-inoculation groups into new cross-inoculation groups as the data collected warrant will be conducive to speeding up the use of cultures specific to the plants on which they are used.

Based on efficiency of nitrogen fixation, sesban was found to belong outside of the cowpea and garden bean cross-inoculation groups, and it was suggested that a "Sesban Inoculation Group" be established (2).[3] Two strains of garden beans used to inoculate sesban produced good and abundant nodules in the greenhouse, but they had no effect on nitrogen fixation in field tests. Six strains of cowpea nodule bacteria produced none to good nodules in the greenhouse, and they likewise had no affect on nitrogen fixation when sesban was grown

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[3]Figures in parenthesis refer to "Literature Cited", p. 278.

in the field. Only cultures isolated from sesban produced efficient nitrogen fixation.

If the mere production of nodules is to be used as the criteria for cross-inoculation groups, sesban could be put into both the cowpea and bean cross-inoculation groups, which suggests that the production of nodules is not sufficient to classify plants for inoculation purposes. It appears, therefore, that efficient nitrogen fixation should be a criteria for placing species of plants in cross-inoculation groups.

The literature reviewed and the interpretation of the data presented previously (1) suggested that placing soybeans outside of the cowpea cross-inoculation group may not be justified. Varietal differences in the response of soybeans to strains of nodule bacteria appeared to be as great as differences between plant species responses within the cowpea cross-inoculation group. It was suggested that emphasis should be placed upon the isolation of strains of nodule bacteria best suited to the different varieties of soybeans and species of the cowpea group rather than placing soybeans in the cowpea group. The data also suggested that strains of soybean root nodule bacteria isolated locally may be superior to strains from other sections of the country.

Orcutt and Fred (3) found under normal light intensity of early summer that inoculated soybeans did not fix nitrogen and that nitrogen fixation was initiated when the plants were partially shaded for one week. The failure of the inoculated soybeans to fix nitrogen under conditions of high light intensity was attributed to excessive quantities of carbohydrates.

Wilson (5) presented data of Baldwin and Hofer on cross inoculation of soybeans and cowpeas when grown in winter and in spring. One cowpea strain and one soybean strain did not cross inoculate in either period, one soybean strain cross inoculated in both periods, and one cowpea strain and one soybean strain cross inoculated only in the spring when the production of carbohydrates was high.

Vetch and Austrian winter peas are grown in the Southeast for green manure crops. They are usually planted in October and November. The growing conditions are such that normally carbohydrate production is low until March. The entrance of the nodule bacteria into the roots and the production of nodules takes place to a large extent during the winter months when the production of carbohydrates is low. On the basis of the data reviewed, it appears that the efficiency of nodule bacteria for vetch and Austrian winter peas which are to be grown in the Southeast may be influenced materially by conditions under which the plants are grown, or by the species of plant from which cultures are obtained.

It is generally considered that inoculation with efficient strains of root nodule bacteria increases both the yield and nitrogen content of legumes, from which one is tempted to make the inference that inoculation with a more efficient strain of nodule bacteria increases both the yield and nitrogen content of legumes. The nitrogen content of inoculated legumes may be a function of both the efficiency of nodule bacteria and the carbohydrates produced. Carbohydrate production is a function of soil fertility and the growing season. The percentage

of nitrogen in well-inoculated soybeans is high when carbohydrate production is low and low when carbohydrate production is high (4).

Data collected in tests of strains of nodule bacteria with soybeans and vetch by the Mississippi Agricultural Experiment Station afforded an opportunity to study the relation of increase in yield to the nitrogen content of soybeans and vetch inoculated with different strains of nodule bacteria, the efficiency of which varied widely, and the effect of source of nodule bacteria on their efficiency.

EXPERIMENTAL PROCEDURE

The soybeans and vetch were grown in the field. The plots were one row, 1/400 acre in size, and there were six replications of each treatment. The plots were layed out in a modified Latin square arrangement. The soybeans were grown on limed and unlimed Lufkin clay soil which had a pH of 4.40 before treatment and received a uniform treatment of 600 pounds of 0–8–4 fertilizer per acre.

The data on soybeans were reported previously (1). The vetch was grown on Myatt fine sandy loan soil and a uniform treatment of 400 pounds of basic slag per acre was made in the drill. The vetch test was conducted in the 1938–39 growing season. The nitrogen determinations for vetch are an average of four to six replications. The data are reported in Tables 1 and 2.

RESULTS AND DISCUSSION

RELATION OF INCREASE IN YIELD TO PERCENTAGE OF NITROGEN IN SOYBEANS INOCULATED WITH DIFFERENT STRAINS OF NODULE BACTERIA

On unlimed soil all strains of nodule bacteria made some increase in yield of soybeans. The increase in yield varied from 39 to 877 pounds of air-dry soybean hay per acre (Table 1). Nine of the 18 strains of nodule bacteria used either failed to increase the percentage of nitrogen significantly or reduced it slightly. Nine strains resulted in a considerably higher percentage of nitrogen in the soybeans. As a whole, the data show that the percentage of nitrogen increased as the yield increased. The data show that the use of inoculation which increased the yield resulted in soybeans containing more nitrogen.

The relation of percentage of nitrogen to the increase in yield of soybeans inoculated with different cultures on unlimed soil was percentage of nitrogen $= 1.33 + 0.0006$ times the increase in yield in pounds per acre. The correlation coefficient (r) between the increase in yield due to the inoculation and the nitrogen content was $.82 \pm .078$, which is very highly significant. The standard error of all of the nitrogen determinations was greater in every case than the difference between the individual averages and the average of all determinations as indicated by the line of best fit to the data.

The strain of nodule bacteria producing the highest increase in yield also produced soybeans containing the highest percentage of nitrogen. If a selection of a strain of nodule bacteria had been made for efficiency, the same selection would have been made on the basis of yield as on the basis of a combination of yield and percentage of nitrogen. These data suggest, therefore, that increase in yield of soybeans due to inoculation is a single factor which may indicate the

TABLE 1.—*The relation of efficiency of nodule bacteria to the increase in yield and nitrogen content of soybeans.*

Unlimed soil			Limed soil		
Culture source	Increase in yield, lbs. per acre*	Nitrogen, %	Culture source	Increase in yield, lbs. per acre*	Nitrogen, %
Midwest soybean, Va.	39±340†	1.42±0.079†	Laredo soybean, Va.	53±327†	1.67±0.241†
Haberlandt soybean, D. C.	157±245	1.44±0.121	Mamredo soybean, Miss.	120±104	1.73±0.178†
Laredo soybean, Va.	183±375	1.41±0.080	Itosan soybean, Va.	183±269	1.69±0.117
Guelph soybean, Va.	237±361	1.45±0.103	Cowpea, Wis.	183±184	1.89±0.093
Mamredo soybean, Miss.	271±346	1.71±0.138	Haberlandt soybean, D. C.	191±263	1.73±0.047
Cowpea, Wis.	313±315	1.45±0.119	Soybean, Fla.	237±308	1.68±0.113
Itosan soybean, Va.	323±337	1.39±0.118	Soysotta soybean, Iowa	296±176	1.61±0.028
Virginia soybean, Va.	371±411	1.52±0.140	Midwest soybean, Va.	337±260	1.63±0.097
Soybean, Fla.	423±341	1.50±0.137	Pimpu soybean, Iowa	404±252	1.89±0.056
Tarheel soybean, Va.	523±363	1.75±0.166	Mamredo soybean, Miss.	404±147	2.02±0.130
Wilson soybean, D. C.	524±355	1.60±0.062	Virginia soybean, Va.	424±243	1.80±0.103
Soysota soybean, Iowa	529±233	1.48±0.153	Cowpea, N. Y.	449±154	1.81±0.178
Tokio soybean, Va.	587±437	1.63±0.153	Wilson soybean, D. C.	477±288	1.75±0.114
Mamredo soybean, Miss.	611±298	1.84±0.134	Tarheel soybean, Va.	509±279	1.83±0.155
Cowpea, N. Y.	673±333	1.71±0.227	Laredo soybean, Miss.	520±303	2.05±0.079
Soybean, Fla.	687±379	1.78±0.105	Soybean, Fla.	564±282	1.81±0.068
Pimpu soybean, Iowa	760±365	1.77±0.097	Guelph soybean, Va.	603±209	1.68±0.110
Laredo soybean, Miss.	877±297	1.89±0.066	Tokio soybean, Va.	843±239	1.95±0.088
Check	1,920	1.47	Check	2,629	1.56

*Air dry hay.
†Standard error.

effectiveness of soybean root nodule bacteria on unlimed soil as well as a combination of increase in yield and nitrogen content.

On limed soil all strains of nodule bacteria produced some increase in the yield of soybeans. The increase in yield varied from 53 to 843 pounds of air-dry soybean hay per acre (Table 1). All strains of nodule bacteria except one produced some increase in the percentage of nitrogen in the soybean hay. The relation of percentage of nitrogen to the increase in yield of soybeans inoculated with different cultures on limed soil was percentage of nitrogen $= 1.54 + 0.0007$ times the increase in yield in pounds per acre. The correlation coefficient between increase in yield and nitrogen content was $.33 \pm .217$, which is not significant. Apparently there was little relation between increase in yield and percentage of nitrogen.

The strain of nodule bacteria producing the highest increase in yield on limed soil also produced soybean hay containing practically as high percentage of nitrogen as was obtained with any strain of bacteria. If a selection of a strain of nodule bacteria had have been made for efficiency, the same selection would have been made on the basis of yield as on the basis of a combination of yield and percentage of nitrogen. As was the case on unlimed soil, these data suggest that increase in yield of soybeans due to inoculation is a single factor which may indicate the effectiveness of soybean root nodule bacteria as well as a combination of increase in yield and percentage of nitrogen.

RELATION OF INCREASE IN YIELD TO PERCENTAGE OF NITROGEN IN VETCH INOCULATED WITH DIFFERENT STRAINS OF NODULE BACTERIA

The inoculation of vetch with different strains of nodule bacteria increased the yield from 405 to 2,302 pounds of air-dry vetch per acre (Table 2). The yield without inoculation was only 197 pounds per acre. The low yield obtained without inoculation and the wide range of increases in yield due to inoculation furnish an excellent opportunity to study the relation of increase in yield to percentage of nitrogen in vetch inoculated with different cultures.

The uninoculated vetch contained 2.82% nitrogen. All strains of nodule bacteria used for the inoculation of vetch increased the nitrogen content at least 0.55%. Strains Nos. 301 and 309 increased the yield 405 and 418 pounds, respectively, of air-dry vetch per acre which contained 3.37% and 3.47% nitrogen, respectively. Where strains of nodule bacteria increased the yield of vetch less than 1,000 pounds per acre, its percentage of nitrogen varied from 3.37% to 3.64%. Where the yield was increased 1,000 to 2,000 pounds per acre, the vetch contained 3.41% to 3.65% nitrogen. Where the yield was increased over a ton per acre, the percentage of nitrogen varied from 3.42% to 3.67%.

The correlation coefficient between increase in yield and percentage of nitrogen in vetch was $.21 \pm .181$, which has no significance. The standard errors of the nitrogen determinations suggest that the differences in the nitrogen content of inoculated vetch are insignificant. The data, therefore, suggest that the increase in yield of

TABLE 2.—*The relation of efficiency of nodule bacteria to the increase in yield and nitrogen content of vetch.*

Culture No.	Source of culture	Increase in yield, lbs. per acre*	Nitrogen, %
301	Wisconsin best on pea	405±132†	3.37±0.206†
309	Mississippi Tangier pea	418±186	3.47±0.176
328	Hairy vetch from commercial culture	688±189	3.42±0.104
315	Mississippi hairy vetch	715±177	3.51±0.245
325	Hairy vetch from commercial culture	745±118	3.47±0.223
304	Wisconsin poor on pea	924± 83	3.56±0.140
312	Mississippi Oregon vetch	991±212	3.64±0.180
308	Mississippi common vetch	1,096±195	3.56±0.149
314	Mississippi common vetch	1,232±113	3.51±0.185
305	Wisconsin good on pea	1,337± 76	3.60±0.177
311	Mississippi purple vetch	1,360±306	3.62±0.073
303	Wisconsin medium on pea	1,474±127	3.57±0.069
307	Mississippi Austrian winter pea	1,852± 98	3.41±0.128
324	Hairy vetch from commercial culture	1,915±135	3.65±0.170
306	Mississippi bitter vetch	2,044±114	3.42±0.170
313	Mississippi Monantha vetch	2,144±149	3.60±0.161
310	Mississippi Hungarian vetch	2,145±131	3.50±0.212
317	Mississippi Austrian winter pea	2,256±124	3.67±0.182
326	Hairy vetch from commercial culture	2,301±215	3.51±0.195
302	Wisconsin medium on pea	2,302±308	3.67±0.088
Check		197	2.82±0.511

*Air dry.
†Standard error.

vetch due to inoculation is a single factor which may indicate the effectiveness of vetch root nodule bacteria as well as a combination of increase in yield and percentage of nitrogen, and that nitrogen determinations are not necessary.

RESPONSE OF VETCH TO STRAINS OF NODULE BACTERIA

The data presented in Table 2 suggest differences in the pea cross-inoculation group or climatic adaptations of strains of nodule bacteria. Strains of pea root nodule bacteria Nos. 301, 302, 303, 304, and 305 were obtained from Dr. I. L. Baldwin of the University of Wisconsin in 1930. They were maintained on low nitrogen media until 1938 when they were used in the tests, the data of which are reported here. A change in the efficiency of the bacteria in the laboratory during this period could possibly have taken place; however, it is assumed in the discussion which follows that their efficiency for peas would have been the same under the conditions under which they were tested in Wisconsin.

Strain No. 301 (Wisconsin best pea strain) increased the yield of air-dry vetch only 403 pounds per acre; strain No. 302 (Wisconsin medium pea strain), 2,302 pounds per acre; strain No. 303 (Wisconsin medium pea strain), 1,474 pounds; strain No. 304 (Wisconsin poor pea strain), 924 pounds per acre; and strain No. 305 (Wisconsin good pea strain), 1,337 pounds. The differences between the increases in yield of vetch for the above five strains of bacteria are

highly significant, except for strains Nos. 303 and 305. The best Wisconsin pea strain was the poorest strain when used on vetch in Mississippi; a medium Wisconsin pea strain was among the best strains for vetch in Mississippi.

These data suggest that hairy vetch should not be placed in the pea cross-inoculation group. However, it should be pointed out that in all probability the Wisconsin pea cultures were used on peas under entirely different conditions as far as carbohydrate production is concerned, and carbohydrate production has been shown to affect the efficiency of strains of nodule bacteria. With either interpretation, the data suggest that strains of nodule bacteria for vetch should be tested on vetch under the climatic conditions under which it is normally grown. Efficiency tests of strains of nodule bacteria conducted in the greenhouse may not supply data which are applicable in the field due to the artificial climate in the greenhouse.

Climatic adaptation of strains of pea root nodule bacteria is also suggested by the data on strains Nos. 324, 325, 326, and 328. These strains were isolated from vetch inoculated with commercial cultures and no doubt were mixtures of strains of root nodule bacteria which had proved efficient in the Middle West where the producers are located. Strains Nos. 324 and 326 increased the yield 1,915 and 2,301 pounds of air-dry vetch per acre, respectively; strains Nos. 325 and 328 increased the yield only 745 and 688 pounds per acre, respectively. These data suggest that strains of nodule bacteria for species of plants in the pea cross-inoculation group should be tested on the species on which it is to be used and in the climate in which the particular species of plant is to be grown.

Strains of nodule bacteria Nos. 306 to 317 were isolated from plants in the pea cross-inoculation group growing on the college farm. The efficiency of these strains of nodule bacteria varied from the lowest to the highest found in the test, which suggests that naturally inoculated soils contain strains of nodule bacteria, the efficiency of which vary throughout the range of efficiency for the group.

SUMMARY AND CONCLUSIONS

Soybeans were inoculated with strains of nodule bacteria with large differences in efficiency and grown on limed and unlimed soil. A similar test was conducted with vetch which received basic slag. The data show that:

1. There was a good correlation between the increase in yield and the increase in nitrogen content of soybeans receiving different strains of nodule bacteria on unlimed soil.
2. There was no correlation between the increase in yield and nitrogen content of soybeans receiving different strains of nodule bacteria on limed soil.
3. All strains of nodule bacteria used on vetch increased the yield and nitrogen content.
4. Even though strains of nodule bacteria increased the yield of air-dry vetch from 405 to 2,302 pounds per acre, only small differences in percentage of nitrogen resulted within strains.

5. The efficiency of good and poor Wisconsin strains of pea root nodule bacteria was reversed on vetch in Mississippi.

The data presented in this paper suggest that:

1. Increase in yield due to inoculation of soybeans and vetch is a single factor which describes the efficiency of soybean and vetch root nodule bacteria, and that nitrogen determinations are not necessary.

2. Climate is a determining factor in the efficiency of pea root nodule bacteria or vetch should not be in the pea cross-inoculation group.

3. Strains of nodule bacteria should be tested on the species of plants on which they are to be used and in the climate the plants are to be grown.

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NITRATE IN PLANTS: ITS RELATION TO FERTILIZER INJURY, CHANGES DURING SILAGE MAKING, AND INDIRECT TOXICITY TO ANIMALS[1]

J. K. WILSON[2]

WHEN excess nitrate is absorbed by plants it accumulates in the sap. According to Bradley, *et al.* (1),[3] the nitrate content of oats grown in a greenhouse equalled 14.4% of the dry weight if calculated as potassium nitrate. They found also that the nitrate content of 10 species of weeds gathered in the open fields ranged from a trace to 8.5% on the same basis.

Olson and Whitehead (9) found the nitrate content of pigweed hay which caused the death of cattle to which it was fed to be equivalent to 6.01% of potassium nitrate. Also, they report that 20 samples of oat hay ranged on the same basis in nitrate from 0.41 to 5.99%, with an average of 3.15%. Additional plants were examined. These included sunflower, corn, sorghum, alfalfa, millet, and spiderwort, all of which contained appreciable nitrate. Seekles and Sjollema (11) found the equivalent of 2% potassium nitrate in dry pasture grass and tried to correlate this with the origin of grass tetany in animals.

Such amounts of nitrate appear rather exceptional, but indicate that where nitrate is available to plants it may be absorbed and represent a considerable percentage of the dry weight. Since these reports are from observations in fairly dry sections, it was decided to determine the nitrate content in the sap of many plants growing with abundant moisture.

CONDITIONS AND PROCEDURE

Plants were taken which had grown under a wide variety of conditions and the nitrate in their saps estimated, following the method outlined by Emmert (3) with certain exceptions. Precautions were taken to prevent the loss of moisture and the sap was expressed at 5–10,000 pounds per square inch in a Carver press and was not treated with charcoal or acetic acid. Aliquots were placed in evaporating dishes, treated with an equal volume of Nl NaOH and the moisture driven off over a steam bath. Then phenoldisulfonic acid was added and allowed to react with the residue in the dishes for at least 10 minutes but not unnecessarily long, for if the acid acted on the residue longer than was necessary for it to combine with the nitrate, carmalization of the sugars from the sap appeared to occur, which reduced at times the accuracy of the method. During this time, the residue was rubbed occasionally with the end of a glass rod. About 15 ml of water were then added, mixed with the contents, and the mixture neutralized with dilute ammonium hydroxide. The color that developed was compared with a standard of known strength. The results are recorded as p.p.m. of NO_3 in the sap of the plant.

All samples of vegetation, unless otherwise noted, were collected during August

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[3]Figures in parenthesis refer to "Literature Cited", p. 289.

and September, 1942. The precipitation during this period was normal or above and the soil never appeared dry. Most of the samples were taken around mid-day or in the afternoon. All the economic plants listed were gathered from cultivated fields, except a few as designated. Many samples of plants commonly called weeds were also taken from stubble lands and from soils producing crops.

PRESENTATION OF DATA

Since several investigators have reported the presence of rather unusual amounts of unassimilated nitrogen in plants, it appeared advisable to express the sap from many plants and examine it for the quantity of nitrate nitrogen it contained. Accordingly, the saps of plants representing 56 genera were analyzed.

NITRATE IN SAP OF CERTAIN PLANTS

Some of the results obtained are presented in Table 1. It is evident that many plants of various genera, if not most of them, may contain an appreciable quantity of nitrate in their sap. Only 1 determination out of 123 gave no nitrate. Three gave only a trace and the other 119 ranged from 68 to 10,000 p.p.m.

NITRATE CONTENT IN SAP OF PLANTS OF VARIOUS GENERA GROWING IN ASSOCIATION

The roots of plants of various genera growing in association in a soil may intermingle and absorb unequally the various nutrients from the soil solution. This may result in a form of competition in which the plants of a genus, or perhaps also of a species within a genus, may absorb and retain more of a certain nutrient than is essential for their development. A rearrangement of some of the data in Table 1 will illustrate how much the plants of two or more genera growing in association may vary in the quantity of unassimilated nitrate in their sap. The comparison is shown in Table 2. In all cases, the plants were near the same stage of development, and the results should represent the comparable abilities of the plants of each genus to accumulate nitrate in their sap from the same soil solution.

It can be seen from the data that plants of various genera growing in association do accumulate different quantities of nitrate in their sap. In one association, soybean contained 1,000 p.p.m., amaranthus 1,429 p.p.m., and purslane 5,882 p.p.m. In another, love grass contained 540 p.p.m., buckwheat 910 p.p.m., and amaranthus 1,400 p.p.m. In still another, oats contained 500 p.p.m., while amaranthus contained 4,140 p.p.m. The nitrate content of plants of other associations is recorded.

NITRATE IN SAP OF CORN

Such quantities of nitrate in plants suggest that crops fertilized with large amounts of nitrogen may contain toxic quantities of nitrate, or enough to modify the finished product should they be made into silage. Accordingly, individual plants of corn were taken from plots fertilized at seedtime with 150, 300, and 600 pounds of $NaNO_3$ an acre. The corn was taken in October before frost and nitrate

TABLE 1.—*Nitrate in the sap of plants.*

Plant	NO_3, p.p.m.
Alfalfa (*Medicago sativa* L.), 2nd cut	570
Artichoke (*Helianthus tuberosus* L.), growing with millet	1,532
Artichoke (*Helianthus tubersus* L.)	870
Awnless brome grass (*Bromus inermis* Leyss), from grass nursery	192
Bean (*Phaseolus vulgaris* L.), cultivated	Trace
Bean (*Phaseolus lunatus* L.), Lima, cultivated	800
Bean (*Phaseolus vulgaris* L. var.), red kidney, grown in greenhouse	10,000
Beet (*Beta vulgaris* L.), tops	433
Beet (*Beta vulgaris* L.), roots of above	1,333
Birdsfoot trefoil (*Lotus corniculatus* L.), 2nd cut	667
Broccoli (*Brassica oleracea* L.)	785
Broccoli (*Brassica oleracea* L.), leaves	221
Broccoli (*Brassica oleracea*, L.), stalk	541
Broccoli (*Brassica oleracea* L.)	3,846
Broom corn (*Sorghum* var.), heading	254
Buckwheat (*Fagopyrum esculentum* Gaerten), in bloom	910
Buckwheat (*Fagopyrum tartaricum* Gaerten), Tartary, in bloom	555
Burdock (*Lappa* sp. Juss)	1,333
Cabbage (*Brassica oleracea*), leaves	2,222
Canada thistle (*Circium arvense* Scop.)	870
Carrot (*Daucus carota* L.), tops	1,176
Carrot (*Daucus carota* L.), roots of above	442
Cauliflower (*Brassica botritis* L.)	2,000
Celery (*Opium graveolens* L.)	1,212
Corn (*Zea maya* L.)	835
Corn (*Zea maya* L.)	487
Corn (*Zea maya* L.)	313
Corn (*Zea maya* L. var.), sweet, ears removed	1,200
Corn (*Zea maya* L. var.), sweet, ears removed	2,000
Crown vetch (*Coronilla varia* L.)	910
Cucumber (*Cucumis sativus* L.), vine	4,170
Cucumber (*Cucumis sativus* L.), fruit of above	121
Cucumber (*Cucumis sativus* L.), fruit	156
Dandelion (*Taraxacum officinale* Weber)	Trace
Flax (*Linum usitatissium* L.), some seeds ripe	522
Jimson weed (*Datura stramonium*), seed starting	1,600
Kafir (*Sorghum cafforoum* Beauv.), heading	952
Kale (*Brassica oleracea* L. var.)	313
Kentucky bluegrass (*Poa pratensis* L.)	170
Ladino clover (*Trifolium repens* L. var.)	Trace
Lettuce (*Lactuca sativa* L.)	1,250
Lettuce (*Lactuca sativa* L. sp.), curly	870
Lettuce (*Lactuca scariola* L.)	666
Love grass (*Panicum capillare* L.), from garden	519
Love grass (*Panicum capillare* L.), growing with buckwheat	540
Love grass (*Panicum capillare* L.), growing with corn	1,110
Meadow fescue (*Festuca elatior* L.)	Trace
Meadow foxtail (*Alopecurus pratensis* L.)	68
Milkweed (*Asclepias* sp.), associating with grass	583
Millet (*Craetochloa italica* Scribn.)	519
Millet (*Panicum miliaceum* Walt.), early fortun	333
Millet (*Panicum miliaceum* Walt.), German	383
Millet (*Echinochloa crusgalli* L. Beauv.), Barnyard	587
Millet (*Echinochloa crusgalli* L.), Barnyard	Trace
Millet (*Echinochloa crusgalli* L.), Barnyard	370
Millet (*Panicum miliaceum* L.), Proso	1,000
Milo (*Sorghum* sp. Beauv.)	740
Muskmelon (*Cucumis melo* L.), vine	1,950

TABLE 1.—*Continued.*

Plant	NO_3, p.p.m.
Muskmelon (*Cucumis melo* L.), fruit of above	433
Oats (*Avena sativa* L.), in dough	505
Oats (*Avena sativa* L.), yellow colored	166
Oats (*Avena sativa* L.), green, in same field as above	606
Orchard grass (*Dactylis glomerata* L.)	166
Orchard grass (*Dactylis glomerata* L.)	435
Orchard grass (*Dactylis glomerata* L.)	370
Orchard grass (*Dactylis glomerata* L.)	870
Orchard grass (*Dactylis glomerata* L.)	280
Peanut (*Arachis hypogea* L.)	91
Perennial ryegrass (*Lolium perenne* L.)	Trace
Pigweed (*Amaranthus retroflexus* L.), associating with soybean	1,429
Pigweed (*Amaranthus retroflexus* L.), associating with buckwheat	1 400
Pigweed (*Amaranthus retroflexus* L.), associating with millet	4,140
Pigweed (*Anmarathus retroflexus* L.), from end of soybean row	5,555
Pigweed (*Amaranthus retroflexus* L.), from garden	1,818
Pigweed (*Amaranthus retroflexus* L.), from test rows of plant	6,250
Pigweed (*Acnida tamariscena* 2n (Nutt) Wood.), from test rows of plant	2,630
Pigweed (*Acnida tamariscena* 4n (Nutt) Wood.), from test rows of plant	667
Pigweed (*Amaranthus retroflexus* L.), from garden lane	2,129
Pigweed (*Amaranthus caudatus* 4n L. var.), from test rows of plant	125
Pigweed (*Amaranthus retroflexus* L.), from oat stubble	5,890
Plantain (*Plantago major* L.), from oat stubble	835
Plantain (*Plantago lanceolata* L.), from oat stubble	1,000
Purslane (*Portulaca oleracea* L.), from among rhubarb	600
Purslane (*Portulaca oleracea* L.), from garden	1,429
Purslane (*Portulaca oleracea* L.), from garden	5,882
Purslane (*Portulaca oleracea* L.), path to garden	200
Purslane (*Portulaca oleracea* L.), from oat stubble	1,175
Purslane (*Portulaca oleracea* L.), from oat stubble	1,175
Red clover (*Trifolium pratense* L.), associating with mixed grasses	218
Red Fescue (*Festuca rubra* L.)	Trace
Red top (*Agrostis alba* L.)	161
Red canary grass (*Phalaris arundinacea* L.)	166
Rhubarb (*Rheum rhaponticum* L.), from garden	571
R. I. bent grass (*Agrostis tenuis* Sibth.)	121
Smartweed (*Polygonum* sp.), from oat stubble	412
Smartweed (*Polygonum* sp.), from edge of corn row	400
Smartweed (*Polygonum* sp.), from near barn	1,160
Sorghum vulgare	334
Sorghum vulgare var. Grohoma	414
Sorghum vulgare var. Early Amber, dark green	278
Sorghum vulgare var. Early Amber, yellow	250
Sorghum vulgare var. Atlas	1,180
Sorghum vulgare var. Wacona	500
Sunflower (*Helianthus annuus* L.), from row in field	425
Soybean (*Glycine max* Piper), from test garden	1,000
Soybean (*Glycine max* Piper), edible, from garden	538
Soybean (*Glycine max* Piper), from test plots	521
Soybean (*Glycine max* Piper), from manured soil	1,250
Soybean (*Glycine max* Piper), from rich soil	850
Squash, in bloom	350
Sweet clover (*Melilotus alba* Desr.), from roadside	700
Sweet potato (*Ipomaca batatus* Lam.)	91
Tall oat grass (*Arrenantherum elatius* (L) Mert and Koch), from specimen row	333

TABLE 1.—*Concluded.*

Plant	NO_3, p.p.m.
Timothy (*Phalum pratense* L.), from specimen row	333
Tomato (*Lycopersicen esculentum* Mill.), vine	853
Tomato (*Lycopersicen esculentum* Mill.), fruit of above vine	None
Vetch (*Vicia villosa* Roth.), from oat stubble	334
Watermelon (*Citrullus vulgaris* Schrod. var.), small fruit	100
Watermelon (*Citrullus vulgaris* Schrod. var.), vine only	1,000
Watermelon (*Citrullus vulgaris* Schrod. var.), fruit of above	1,000
Watermelon (*Citrullus vulgaris* Schrod. var.), vine only	10,000
Watermelon (*Citrullus vulgaris* Schrod. var.), fruit of above	500
Yellow oxalis, edge of corn rows	500

TABLE 2.—*Ability of plants growing in association to accumulate nitrate in their sap from the soil solution.*

Plants growing in association	NO_3 in sap, p.p.m., respectively
Soybean, amaranthus, portulaca	1,000, 1,429, 5,882
Millet, artichoke	383, 1,532
Oats, amaranthus	500, 4,140
Love grass, buckwheat, amaranthus	540, 910, 1,400
Rhubarb, portulaca	751, 600
Amaranthus caudatus 4n, portulaca	125, 1,175
Amaranthus, portulaca	5,555, 5,882
Love grass, soybean, amaranthus	519, 1,000, 1,818

determined in the expressed sap of the stalk above and below the ear and in the blades. The findings are shown in Table 3.

TABLE 3.—*Nitrate in sap of parts of individual corn plants.*

$NaNO_3$, lbs. per acre	Plant No.	Nitrate in sap, p.p.m.		
		Above ear	Below ear (stalks)	Blades
None	1	372	372	909
	2	464	114	500
150	1	263	154	979
	2	500	571	625
300	1	343	120	762
	2	457	125	791
600	1	322	2,328	632
	2	505	1,000	800

The data confirm and extend the findings shown in Table 1, i.e., that considerable amounts of unassimilated nitrogen may be present in the sap of plants. Although the quantity found in plants that were taken from soil that had received 600 pounds of $NaNO_3$ an acre at seedtime is probably below that required to injure animals, it ap-

proaches that quantity closely, and indicates that, under less humid conditions, toxic amounts may accumulate. If there are 2,000 p.p.m. of nitrate in the sap and the sap represents 80% of the green weight, then the quantity of nitrate as a sodium salt is equal to about 1.10% of the dry weight.

NITRATE IN SAP OF MUSKMELON CORRELATED WITH ABNORMAL APPEARANCE OF PLANTS

In Table 1 it is recorded that a muskmelon vine contained 1,950 p.p.m. of nitrate in its sap. This vine was representative of many growing in the field from which the better melons had been removed for market. At the time of collection, no thought was attached to the rather ragged appearance of the vines, but when this quantity of nitrate was found to be present, it suggested that perhaps this abnormal appearance was correlated with the quantity of nitrate in the sap of the plant. Previously, it had been observed that muskmelon growing on a soil in a greenhouse exhibited somewhat similar appearances. Such plants were examined by a pathologist and by a physiologist, but no helpful information was obtained concerning the abnormal condition.

The first symptom indicating that the plants were abnormal was a yellowing of the leaves at the base of the plant. This condition gradually moved up the plant. Sometimes the leaves became mottled, then scorched, and finally dry. Each of these conditions usually progresses upward, and any one plant may show all of these stages of abnormality. In nearly all cases, when this condition started, it was no longer profitable to grow the plants. Many of them actually died.

In the summer of 1942 muskmelons were being grown in water culture in a greenhouse. When the abnormal condition developed, no signs of pathological infection were noted. The plants showed the progressive abnormality so badly that it appeared unprofitable to culture them any longer. At this stage certain plants and certain portions of plants were taken for a determination of their content of nitrate. The results of these tests are shown in Table 4.

From the data it appears safe to say that the increasing severity of the abnormal condition of the melon vines runs parallel with the increase of nitrate in the sap of the tissues. The worst burning and drying up of the leaves occurred where there were 2,000 p.p.m. of nitrate or more in the sap. Those plants and parts of plants which appeared most normal contained the least quantity of nitrate.

SEVERITY OF SCORCHING OF SNAPDRAGON AND NITRATE CONTENT IN SAP

A disturbance somewhat analagous to the one described for muskmelon has been observed to produce scorching of leaves and stems of snapdragon (*Antirrhinum majus*). It has been encountered by florists ever since the plant has been grown as a winter greenhouse crop. It appears during the short cloudy days of midwinter and disappears when the longer days toward spring return.

The scorching is characterized by certain fairly easily recognizable

TABLE 4.—*Nitrate in the sap of muskmelon in relation to increasing abnormal appearance of the plants.*

No.	Condition of plant	NO_3 in sap, p.p.m.
1	Leaves yellow, pre-mottled stage, none scorched	577
2	Leaves mottled, pre-scorching stage, none burnt	682
3	Short runners and ends of vines, some burnt, some scorched	1,250
4	Vine, heavily scorched, burnt at bottom, upper part and edges of leaves scorched	2,000
	Fruit, 275 grams	893
	Roots	500
5	Vine, top ⅓ all stages of burning and scorching	1,190
	Middle ⅓ mostly scorched or badly burnt	2,000
	Lower ⅓ leaves almost too dry to get sap	1,531
	Roots	182
6	Vine above fruit badly scorched	1,333
	Below fruit badly burnt	1,818
	Fruit, 460 grams	385
7	Vine above fruit scorched and burnt some	1,818
	Below fruit badly scorched, badly burnt	2,105
	Fruit, 210 grams	400
	Roots, dried some before pressed for sap	560
8	Vine upper ½ abnormal	545
	Lower ½ abnormal	413
	Roots dried some before pressed for sap	257
9	Vine scorched badly, burnt a little	1,000
	Fruit only	590
	Roots	125
10	Vine abnormal	700
	Fruit only	483
	Roots dried some before pressed for sap	666
11	Nutrient solution from around roots	0

symptoms. Many leaves that have just reached full size and some tender stems, usually on the middle one third of the plant, show a progressive scorching and drying. This may continue for several days before it reaches the petiole and finally the stem of the plant. The affected tissue of the leaf appears collapsed and somewhat water-logged. Occasionally, the disturbance may appear as an acute triangle on the outer end of the leaf, with the triangle pointing toward the petiole. Each advance, of which there may be several, may be noted in the form of bands across the leaf which retain much of the green color but assume a slightly glossy metallic appearance. This color may bleach in the sunlight. If the progress is rapid, the part of the leaf affected droops and hangs almost straight down and dries in this position. When the next part of the leaf droops and dries, it forces the already partly dried leaf either downward or upward and produces the appearance of waves or bands on the mummified leaves. When the petiole and young stems are badly affected, they may appear almost black. The first symptom on the main stem may be one or more brown or black areas which may increase in size and coalesce. The leaves and parts thus affected may remain on the plant but, subsequently, may shatter when the plant is handled.

On December 15, 1942, normal appearing plants and others

exhibiting various degrees of scorching were submitted for analysis by the Department of Floriculture. These were pressed for their sap and aliquots of each used for a determination of nitrate. The plants were growing on a soil that had received mineral fertilizers and tankage and were watered from below by irrigation. The results are available in Table 5.

TABLE 5.—*Severity of scorching of snapdragon in relation to content of nitrate in sap.*

Condition of plants	NO_3 in sap, p.p.m.
Normal appearing	1,638
First stage or scorching	1,800
Advanced stage of scorching	2,124
Badly scorched or burnt and parts badly drooping	2,286

It is apparent from the data that the increase in severity of scorching runs parallel with the increase of nitrate in the sap. The apparently normal plants contained in their sap 1,638 p.p.m. of nitrate, while those badly scorched and badly drooping contained 2,286 p.p.m. Tests for nitrite in these saps were negative.

Such data were taken to indicate that the soil on which these plants grew were fairly rich in nitrate; accordingly, the crust at the surface was taken for analysis. The results showed about 9,375 p.p.m. in the sample on a moisture-free basis. This is equal to about 1.3% of the dry weight of the soil if calculated as sodium nitrate. Tests made by the Department of Floriculture for nitrate in the first 4 to 5 inches of the top soil indicated that only 75 to 100 p.p.m. were present in the moisture of the soil.

DISCUSSION AND POSSIBLE SIGNIFICANCE OF DATA

In making a determination of the nitrate content of the sap of plants it was assumed that the moisture expressed from the plant was a representative sample of the moisture of the whole plant. This may or may not be true. Also, a fluctuation of the moisture in the vegetation should modify the p.p.m. of nitrate. Nevertheless, the nitrate in the sap represents a definite amount as being present in the plant when examined. Such plants may be dried as hay, fed to animals, or siled. If they are siled, conditions are imposed which appear favorable for partial or complete reduction of the nitrate with a loss of gaseous nitrogen through one or more reactions. If they are dried as hay, the nitrate may represent a considerable portion of the dry matter. Plants such as bean, pigweed, and watermelon vine may contain 5,000 p.p.m. of nitrate in the sap and the sap may represent 85% of the total weight. Thus, it is evident that this nitrate calculated as $NaNO_3$ would constitute about 3.88% of the dry weight. The data show that beans grown in the greenhouse and vines of watermelon contained twice this quantity.

According to certain investigators this percentage of nitrate should be lethal to animals. Bradley, *et al.* (1) say, on the basis of their ex-

periments, that it is necessary for a 500-pound animal to eat only about 5½ pounds of hay containing 5% of KNO_3 to be fatally poisoned. The limited data presented in this paper concerning the nitrate in corn grown with abundant rain and heavily fertilized with $NaNO_3$ show only slight chances that lethal concentrations will be present in the mature crop when grown with medium applications of $NaNO_3$.

Soils heavily fertilized with nitrate and vegetation known to contain nitrate have been associated with or considered the direct cause of such animal disturbances as (a) corn stalk disease (7); (b) oat hay poisoning of various farm animals, including poisoning by weedy barley hay and wheat straw (1, 9, 14); (c) borna disease of horses (13); (d) grass tetany of cattle (2, 4, 5, 6, 11, 12); and (e) bloat in animals from eating pigweed (8).

An inspection of Table 1 will show that grasses in contrast to many other plants contain mostly only a trace of nitrate in their sap or only a few hundred p.p.m. Whether this is due to a deficiency of one or more nutrient salts in the soil, to the time of year that the plant was examined, or to some other factor is unknown. It might be related to the degree of guttation through which the nitrogen is largely returned to the soil, for grasses as a class probably guttate more abundantly than do such plants as beans, clover, sunflower, oats, corn, or pigweed.

The toxic effect of vegetation containing nitrate apparently is not due to the nitrate as such. When the nitrate is ingested it passes into an environment where oxygen is in demand, the nitrate is thus reduced to nitrite and the latter is toxic. This nitrite, once in the blood stream, according to Bradley, *et al.* (1), combines with the blood producing methemaglobin, preventing the blood from supplying oxygen to the tissue, thus the animal suffocates. If this reduction occurs in the paunch of an animal where there is a considerable range of acidity, conditions obtain for a reaction to occur between nitrous acid, amides, and other substances with a liberation of gaseous nitrogen. The basic radicle to which the nitrate was attached would tend to stabilize the acidity in the paunch, neutralizing that produced by the bacteria and by the animal membranes, and thus extend for some time the conditions suitable for a reduction of nitrate. Should this occur, it brings a direct relationship between the nitrate content of vegetation and the occurrence of one kind of bloat in animals.

Newsom and Stout (8) describe observations which make this suggestion stand out in relief. They report that late rains brought up pigweed on soil previously dry, that animals ate the weed freely, that some of them got bloat and died, that others aborted, that the disease was similar to poisoning by hydrocyanic acid, and that the poison was present in a variety of forage plants.

Also, a report by Crawford (1941) confirms this idea. Sixteen cattle died within a few hours after grazing on a portion of a rubber estate which had been dressed the previous day with nitrate of soda. Among the symptoms were bloating and distress.

It is apparent from the data presented in this paper, as well as from those presented by Bradley, *et al.* (1) and Olson and White-

head (9), that pigweed usually contains a high percentage of nitrate, and Bradley, *et al.* (1) point out the similarity of poisoning by nitrite to that of poisoning by hydrocyanic acid. However, they fed crops containing lethal amounts of nitrate and administered saltpeter but record no bloating of animals.

The nitrate content of such vegetables as beets, broccoli, cabbage, cauliflower, lettuce, etc., suggests that these foods may be toxic at times to humans. Undoubtedly, some of the nitrate will be reduced to nitrite in the digestive tract and, as such, may be absorbed into the blood where it will produce nitroso-hemaglobin. Since more than 50% of the blood must be thus inactivated before toxic conditions are manifest and since humans consume small amounts of such vegetables at any one time, it appears unlikely that the nitrate from this source alone will be very often indirectly dangerously poisonous to them. Reference to such a poisoning has not been found in the literature.

A disturbance of cucumber growing in a greenhouse was studied by Schroeder (10) who correlated the severity of the trouble with a lowering of the temperature of the root system. This cooling of the roots resulted in a subsequent wilting because, once sufficiently cooled, the plants could not absorb water as fast as it was lost from their surfaces. This resulted in scorching. The only determination of the nitrate in a cucumber plant growing in a vegetable garden gave 4,170 p.p.m. There may be some relation between the nitrate content of cucumber and the disturbance studied by Schroeder.

The presence of nitrate in crops being siled may have a striking effect on the resulting product. Some or all of the nitrogen in the acidic nitrate ion may be reduced to ammonia, and as such, function as a cation. Therefore, the acidic and basic properties of the siling material will be changed. If the vegetation being siled contains 2,000 p.p.m. of nitrate in the sap, which represents 80% of the weight, then by calculation, it appears that there can be enough base developed during fermentation to be equivalent to the neutralizing power of 4.13 pounds of sodium hydroxide in each ton of fermenting material. Such an amount of basic substance coming from what was originally a neutral salt, must be acidified along with the vegetation itself at the expense of the fermentable carbohydrates before the desired pH value can be reached in the siling mass. It will require about 9.27 pounds of lactic acid to neutralize these bases, or this quantity of base will neutralize one acid hydrogen of the three in 10.90 pounds of pure phosphoric acid.

A considerable period of time may be required to accomplish this change. This may lead to a vicious circle, producing disastrous results. The vitamins and other desirable compounds may be reduced or destroyed through putrefactive activity. Also, the neutralization of the organic acids by these bases, as well as by others that may develop, may modify the quality and palatability of the silage or even destroy its usefulness.

If all the nitrate in the crop being siled is not reduced or drained away, it will be consumed when the silage is fed. It should function

in the animal in the same manner as though it were ingested in the freshly gathered crop.

SUMMARY AND CONCLUSIONS

Plants were gathered from a variety of locations and conditions and their sap expressed under pressure of about 10,000 pounds per square inch. They represented 56 genera.

Aliquots of the sap were evaporated to dryness and the nitrate determined colorimetrically. It ranged from a trace to 10,000 p.p.m. Only 11 determinations of 123 showed as little as 100 p.p.m., while 78 showed between 100 and 1,000 and 23 between 1,000 and 2,500. Only 10 were above these amounts.

Plants such as pigweed, purslane, and smartweed contained as much nitrate or more in their sap as did many cultivated plants. Legumes as well as nonlegumes may accumulate relatively large amounts of nitrate.

It appears that species of various genera of plants growing in association accumulate different amounts of nitrate.

The relation of this nitrate in vegetation to certain plant, animal, and human disturbances is discussed and its influence on the quality and palatability of silage emphasized.

From a limited number of tests of the nitrate in corn that was heavily fertilized and nearly mature, it appears unlikely that lethal quantities of nitrate will accumulate in corn in humid sections.

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LATTICE AND LATTICE SQUARE DESIGNS WITH OAT UNIFORMITY DATA AND IN VARIETY TRIALS[1]

I. J. Johnson and H. C. Murphy[2]

SINCE 1936, when lattice and lattice squares were described by Yates (7),[3] fairly extensive application has been made of these designs in conducting yield trials of crop varieties. Most of the published data comparing their precision with randomized complete blocks have been made from corn yield tests and uniformity data. The comparative accuracy of lattice and lattice square experiments in comparison with the analysis as randomized blocks with corn yield tests at the Iowa Agricultural Experiment Station summarized by Cochran (3) showed that on the average three replications of a triple lattice were somewhat more accurate than five replications of the randomized complete blocks formerly used. The relative precisions varied from 114 to 365%. In the lattice square designs the relative precision ranged from 98 to 462% with an average saving of one replication in six for tests of 25 varieties to one replication in three for tests with 121 varieties. From a study of corn uniformity trial data, Zuber (9) found a relative precision of 136% as an average for lattice, triple lattice, balanced lattice, and lattice square designs with 25, 49, 81, and 121 assumed varieties, respectively. The relative precision of lattice squares was greater than from lattice and triple lattice designs, and the precision with the smaller number of varieties was somewhat greater than for the larger tests. Weiss and Cox (6) found a considerable gain in precision from the use of balanced incomplete block and lattice square designs in soybean trials.

Data comparing the precision of incomplete block designs in small grain rod row tests are very limited. Goulden (4) from a study with Wiebe's wheat uniformity trial data obtained increases of 67 and 87% with two 6×6 designs. With barley uniformity data the precisions ranged from a loss of 37% in long and narrow incomplete blocks to a gain of 18% in compactly shaped blocks. As reported by Cochran (2), six experiments by Dr. L. R. Waldron at the North Dakota Agricultural Experiment Station using lattice designs with 49 to 169 wheat varieties gave no gain in two tests, a 2% gain in one test, and 39, 45, and 156% gains in the remaining three tests.

In general, the gain in precision from the use of lattice and lattice square designs has been sufficiently great to justify their use particularly in tests with large numbers of varieties. The principles underlying the use of these designs in crop variety tests and methods of

[1]Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, cooperating with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture, Project 654. Journal paper J-1070 of the Iowa Agricultural Experiment Station. Received for publication December 17, 1942.

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[3]Numbers in parentheses refer to "Literature Cited", p. 305.

calculation have been given in papers by Yates (7, 8), Cox, Eckhardt, and Cochran (1), Goulden (5), and Cochran (2), and will not be restated here. The field arrangement when the varieties to be tested are divided into incomplete blocks presents no serious difficulty and often may be advantageous in nursery plot work. The statistical analysis of the data when these designs are used, although somewhat more complex than for randomized complete blocks, is not difficult when the procedures have become fully understood.

The objectives in the present investigation were to determine the relative precision of lattice and lattice square designs when superimposed on uniformity trial data with oats in which different field arrangements of the incomplete blocks could be studied with 8- and 16-foot long plots and to determine their gain in actual variety trials with oats conducted for the past two years (1941–42).

MATERIALS AND METHODS

The field selected for the uniformity trial was representative of those used for experimental purposes in crop variety studies. The oat variety Vikota, C.I. 3602, a rust- and smut-resistant selection from Victoria×Richland, was planted with a Columbia nursery planter in 1-foot rows at the rate of 3 bushels per acre. The entire area for this study consisted of 219 rows 168 feet long. The stand was excellent and uniform within the row and very little lodging occurred during the season. An average yield for the entire area of 64 bushels per acre represents approximately normal performance for oats on the experimental plots on the Iowa Agricultural Experiment Station Agronomy Farm.

At harvest time a 4-foot border was removed and successive 8-foot single rows were harvested. Between alternate ranges of 8-foot plots a 2-foot area was removed to simulate an alley between 16-foot plots. Sufficient material was thus available for 18 ranges of 8-foot plots on 219 rows, or a total of 3,942 single plot units.[4] The plots were threshed with the small grain nursery thresher when thoroughly dried.

The plot weights were then combined by adding the appropriate 8-foot rows to make up the center row of three-row plots 16 feet long and also to make the two center rows of four-row plots 8 feet long. A total of 657 three-row plots 16 feet long and 990 four-row plots 8 feet long were available for study.

Three kinds of designs were included in the study, namely, simple lattices with two groups of sets (four replications), triple lattices, and lattice squares assuming 25, 36, 49, and 81 varieties for the simple and triple lattice designs and 25, 49, and 81 varieties for the lattice squares. With very few exceptions a plot was used only once in a particular design, and as many tests of a design were analyzed as could be made up with the data available.

The statistical analysis of uniformity trial data by the intra-block method for lattice designs is different from that for actual variety tests because the variety component is eliminated and the block, or column and row totals, are not confounded with varieties. The analysis of variance (Table 1) of a 5×5 triple lattice design illustrates the procedure used in this study.

The total sums of squares and the sums of squares for replications are obtained

[4]The original data are filed in the Farm Crops Subsection of the Iowa Agricultural Experiment Station and are available to those who wish to make additional studies with these data.

TABLE 1.—*Analysis of variance of a 5 × 5 triple lattice design.*

Source of variation	D.F.	S.S.	M.S.	Ef.
As 5 × 5 Triple Lattice				
Total	74	100,907.6	—	—
Replications	2	25,714.4	—	—
Blocks (ignoring varieties)	12	43,374.4	3614.5	—
Error	60	31,818.8	530.3	635.7
As Randomized Block				
Total	74	100,907.6	—	—
Replications	2	25,714.4	—	—
Error	72	75,193.2	1044.4	—

$$\text{Precision} = \frac{1044.4}{635.7} = 164.3\%$$

in the usual manner. The sums of squares for blocks in the simple and triple lattice designs were obtained by squaring the block totals, dividing by k, subtracting the correction factor, and subtacting the sum of squares for replications. In the lattice square designs the sums of squares for rows and columns were obtained as outlined above for blocks. The effective error mean square per plot, Ef, is the product of the error mean squares and the f values as given below.[5] The f values are needed to take account of the sampling error of the block (or row and column) adjustments. Unless otherwise noted the error variances given in subsequent tables are the effective mean squares per plot.

Type of Design	f
k×k simple lattice	$1+\dfrac{2(B-E)}{(k-1)\,(B+E)}$
k×k triple lattice	$1+\dfrac{3(B-E)}{(k+1)\,(2B+E)}$
k×k lattice square $\left(\dfrac{k+1}{2}\right)$ rep.	$1+\dfrac{\frac{1}{2}(R-E)}{E+\frac{1}{2}(k-1)R}+\dfrac{\frac{1}{2}(C-E)}{E+\frac{1}{2}(k-1)C}$

B, R, C, and E are mean squares for blocks, rows, columns, and error, respectively, and k is the number of varieties per incomplete block.

The comparisons with actual yield data were obtained from 8-foot and rod-row tests of oat varieties and selections grown in three-row plots from which the center row was harvested and in single-rod rows. These tests in cooperation with the U. S. Dept. of Agriculture, Division of Cereal Crops and Diseases, were grown at Ames and Kanawha, Iowa, in 1941 and 1942. In the variety trial data the analysis for the recovery of inter-block information was employed as outlined by Cox, Eckhardt, and Cochran (1) for lattice designs and by Yates (8) for lattice squares.

EXPERIMENTAL RESULTS

LATTICE AND LATTICE SQUARE DESIGNS WITH UNIFORMITY TEST DATA

The field arrangement of incomplete block designs may have considerable bearing on their relative precision when compared with a

[5]Prepared by Prof. W. G. Cochran, Statistical Section, Iowa State College. It should be noted that these formulae are valid only when uniformity data are used.

randomized complete block experiment. For the simple and triple lattices the blocks may be arranged to fit most conveniently the experimental area, but in lattice squares the position of rows and columns must conform to a definite position on the field. The different types of field arrangements for simple or triple lattice designs have been illustrated by Cox, Eckhardt, and Cochran (1) and by Zuber (9) for corn yield test plots and will not be repeated here because the principles apply equally to small grain rod-row trials. It is generally recognized that a compact nearly square complete replication in randomized blocks is likely to give a lower error variance than a long and narrow replication. The general viewpoint that long plots are superior to short, wide plots may not necessarily be the result of plot shape, but may be due to the modificatuon of replication shape resulting from differences in length and width of the plots within the replication.

A study was made on the relation between replication shape and the error variance with the 6×6 triple lattice designs in which the six blocks were placed side by side and also in three ranges of two incomplete blocks for each of groups x, y, and z. In the first arrangement each replication was 16×108 feet for three-row plots 16 feet long and 8×144 feet for four-row plots 8 feet long. In the second arrangement the complete replication, including alleys, was 52×36 feet for the 16-foot plots and 48×28 feet for the 8-foot plots. In this study, the same plots could be used in the rectangular and the more compactly arranged complete replication. Six sets of 16-foot plots and a similar number of 8-foot plots were studied with the data available. The results given in Table 2 show that the error variance for the randomized complete block design was considerably higher in the long and narrow arrangement of plots than in the more compact shape replication. The variance for the triple lattice design, however, was modified only slightly by the field arrangement of the incomplete blocks. The

TABLE 2.—*Error variance for 36 varieties arranged as 6 × 6 simple and triple lattices and as randomized complete blocks and the relative precision of the lattice designs for 16- and 8-foot plots.*

Type of design	No. of replications	No. of tests	Shape of replicate, feet	Error mean square		Average relative precision, %
				Lattice design	Randomized block	
Center Row of Three-row Plot 16 Feet Long						
Simple lattice	4	6	36 × 52	621	972	156
Triple lattice	3	6	36 × 52	618	953	161*
Triple lattice	3	6	108 × 16	635	1,100	172*
Center Two Rows of Four-row Plot 8 Feet Long						
Simple lattice	4	6	48 × 28	612	946	154
Triple lattice	3	6	48 × 28	601	983	163*
Triple lattice	3	6	144 × 8	614	1,302	215*

*Same plots used in both tests.

relative precision of the triple lattice was higher for the long narrow replication which would naturally follow from the higher variances of the randomized blocks. As pointed out by Cochran (3), the gain in precision of an incomplete block design may be a maximum value in some comparisons when the replication shape is not desirable from the standpoint of the randomized complete block.

The error mean squares for the 6×6 triple and simple lattices cannot be compared directly because the same plots were not used in both comparisons. The average error variance per plot of the two designs, however, was very similar, and both were much lower than when analyzed as randomized complete blocks. The gain in precision of these lattice designs when arranged in a compact replication was approximately equivalent to an increase of from one to two replications as a randomized block experiment.

The error mean squares and precision for 25 varieties arranged in simple lattices, triple lattices, and lattice squares, in comparison with randomized complete blocks are given in Table 3. For both the 16- and 8-foot plots the incomplete blocks of the triple lattices were laid out in two ways, *viz.* in five ranges of five plots each per replication to compare this design with the lattice square utilizing the same plots in each test and in a single range of 25 plots. The simple lattice designs were arranged only in a single range of 25 plots per replication. The opportunities for different types of arrangement of the five incomplete blocks in a 5×5 simple or triple lattice design are limited, and in actual practice 25 varieties in rod-row plots are usually arranged side by side in each replication.

From the data in Table 3, from ten tests with 16-foot plots and nine with 8-foot plots, the lattice square gave a considerably lower error variance than the triple lattices on the same plots, indicating

TABLE 3.—*Error variance for 25 varieties arranged as 5×5 lattice and lattice squares and as randomized complete blocks and the relative precision of the lattice designs for 16- and 8-foot plots.*

Type of design	No. of replicates	No. of tests	Shape of replicate, feet	Error mean square: Lattice design	Error mean square: Randomized block	Average relative precision, %
			Center Row of Three-row Plot 16 Feet Long			
Triple lattice	3	10	15×88	567	1,032	190*
Lattice square	3	10	15×88	498	1,032	221*
Simple lattice	4	6	75×16	673	1,215	185
Triple lattice	3	9	75×16	586	1,158	183
			Center Two Rows of Four-row Plot 8 Feet Long			
Triple lattice	3	9	20×48	576	789	137*
Lattice square	3	9	20×48	506	789	158*
Simple lattice	4	9	100×8	609	1,090	177†
Triple lattice	3	12	100×8	586	1,090	186†

*Same plots used in both designs.
†Same total plots used in both designs.

that the variance removed by columns in the lattice square more than compensated for the loss of 12 degrees of freedom from the error. The gain in precision of both the triple lattice and lattice square designs in the 16-foot plots was very high when compared with randomized blocks, and in these studies their standard error of the mean of three replicates would be approximately equal to that obtainable from six replications in a randomized block experiment. The precision of the comparable triple and lattice square design with 8-foot plots was not as large as for the 16-foot plots. Although the error mean squares for each design were essentially the same on the two types of plots, the variance for the randomized block with 8-foot plots was considerably lower than for the 16-foot plots. As shown in Table 2, a lower error for the randomized block would have been expected on the basis of the more compact replication shape in the 8-foot plots than for a similar arrangement with the 16-foot plots. These data serve to emphasize the fact that plot shape does not influence the variance of a randomized complete block as much as does the shape of the replication.

The comparative advantages of the simple and triple lattices could be determined from their respective variances when the plots were laid out on a long, narrow strip. For the 16-foot plots, the error mean squares of 673 and 586 are not directly comparable because the same plots could not be used for each to secure the maximum utilization of the uniformity data. In the 8-foot plots, however, the same total plots were used in the two designs, and hence the variances 609 and 586 for the simple and triple lattice can be legitimately compared. Although this difference is small, the slight advantage for the triple lattice over the simple lattice is in agreement with results obtained by Zuber (9). The variances for the 8- and 16-foot plots were approximately the same as was the precision when compared with randomized blocks.

The gain in precision of all 5×5 incomplete block designs was surprisingly high. The coefficient of variability for the center row of all 16-foot plots on the area studied was only 13.45%, a value not greatly above that obtained in many small grain rod-row tests. From an examination of the soil heterogeneity map (Fig. 1) it would be expected that in certain areas the gain would be greater than in other parts of the field. The relation between soil heterogeneity and gain in precision from the use of incomplete block designs can best be illustrated with the 5×5 triple lattices with 8-foot plots in a single range of 25 plots per replication. The 12 designs studied utilized the entire width and all but 19 feet of the length of the field. Groups x, y, and z were in all cases in adjacent ranges, and each test therefore utilized three ranges of 25 plots each (100 rows or 12.5 plots in Fig. 1).

The variations in precision of the 12 tests of this design are shown in Fig. 2, which is drawn to the same scale as Fig. 1. Test No. 5 on ranges 13–15 and four-row plots 1–25 gave a precision of 313% with the randomized blocks as 100%. The soil in this area of the field was extremely heterogeneous, varying in yield from 55 to 75 bushels per acre. Since the yield contour lines were largely at right angles to the direction of the replication, the blocks removed a large part and replications only a small part of the total variability. The precision for

test No. 12 on ranges 16–18 and four-row plots 26–50 was very low, 106%. The yield variation in this area was only from 65 to 70 bushels per acre. These two extremes illustrate the differences in precision that may be expected on variable and uniform soil. Test No. 8 on

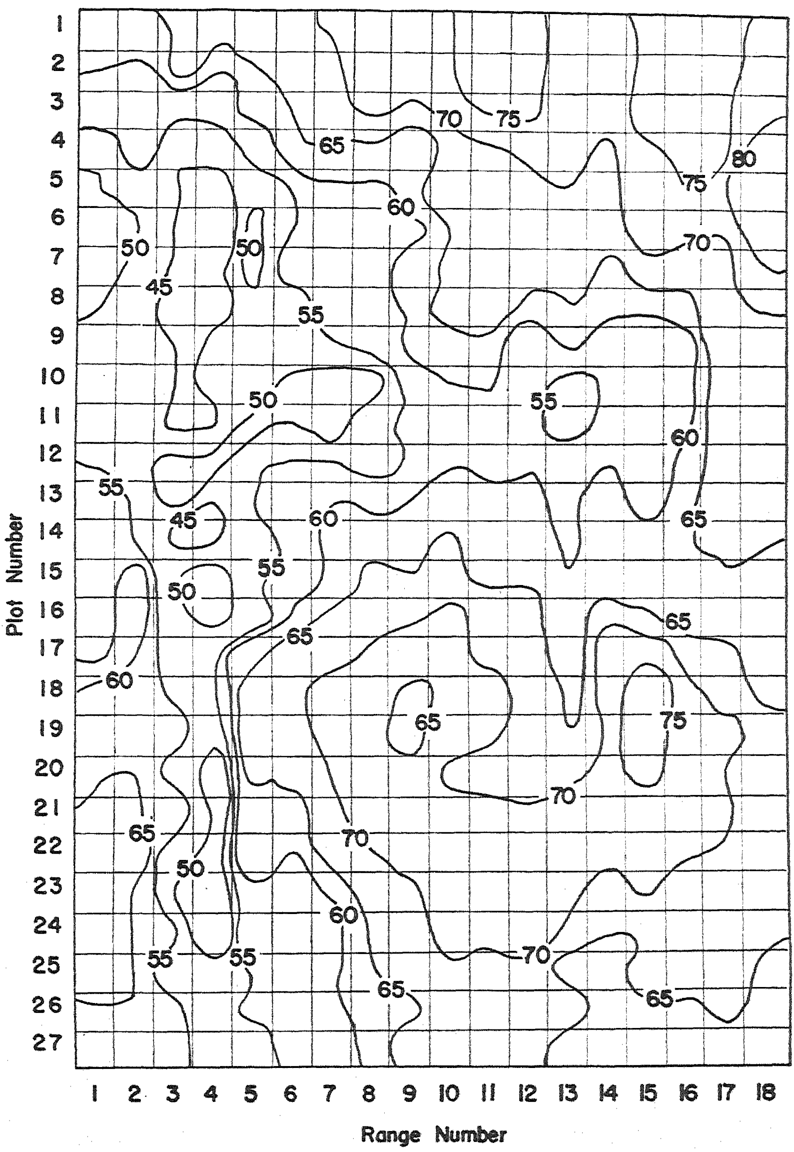

FIG. 1.—Soil heterogeneity map of field used in the uniformity trial. Each plot unit eight rows 8 feet long. Yields are in bushels per acre.

ranges 4–5 and plots 26–50 illustrates the relation between the direction of soil heterogeneity lines and the variance removed by blocks. In this area the yields varied from 45 to 65 bushels per acre, a range comparable to that in test No. 5, but the variation in yield was

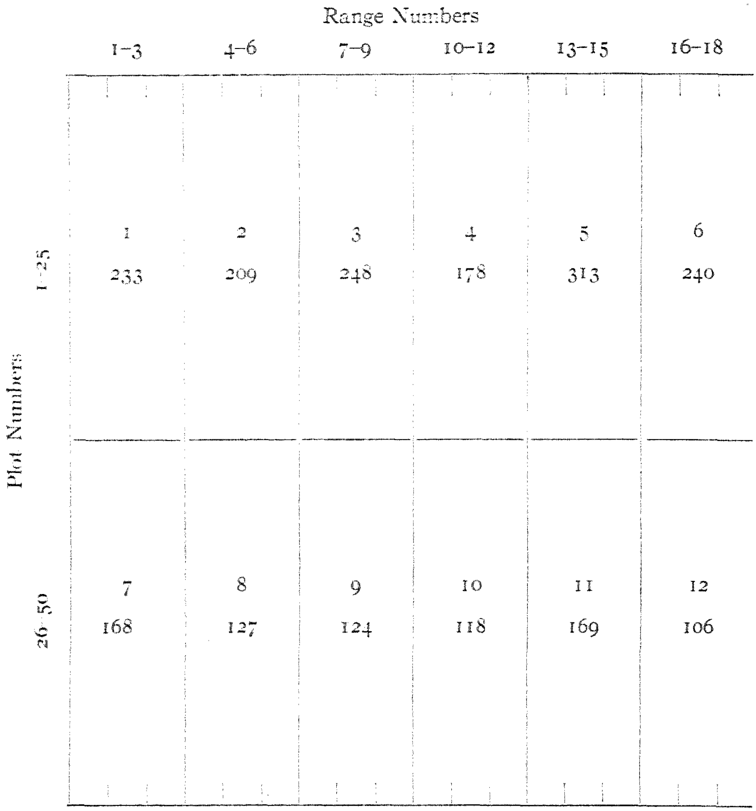

FIG 2.—Precision of 5 × 5 triple lattice designs with four-row plots 8 feet long in different areas of the uniformity trial.

largely parallel to the replications and hence replications effectively removed the major part of the variation. The efficiency of the design in this area was 127%. If the fertility gradient of an experimental site were known in advance, the field plant of the incomplete blocks could be arranged to remove variability most effectively within the complete replication.

As shown in Table 3, the lattice square designs for both the 16- and 8-foot plots gave a lower error variance than that obtained from the triple lattice designs on the same plots. In small grain rod-row trials utilizing the center row of a three-row plot 16 feet long, the shape of the square (replication) of a lattice square design is long and narrow. For a 5 × 5 lattice square the actual dimensions in this study,

including a two-foot alley between ranges, was 88 feet long and 15 feet wide. In four-row plots 8 feet long with the center two rows harvested the dimensions of the square were 48 feet long and 20 feet wide. It would be expected that the variance for rows would be considerably greater than for columns, particularly in the 16-foot plots, and that the variance for columns might not be sufficiently great to justify the loss of 12 degrees of freedom from the error. A comparison of the row and column variances together with the unadjusted error variances given in Table 4 indicates that the first supposition was correct and the second was not. In the 16-foot plots the variance for rows was 4.55 times greater than for columns corresponding to the replication length of 5.87 times greater than its width. The column variance, however, was over twice as great as the error variance. In the 8-foot plots the variance for rows was 2.54 times greater than for columns in close agreement with the ratio of length to width of the replication.

TABLE 4.—*Comparison of row, column, and unadjusted error variances in 5×5 lattice square designs with 3×16- and 4×8-foot plots.*

Plot length, feet	No. of tests	Variance due to			Variance of row/column	Replication length/width
		Rows	Columns	Error		
16	10	3,778	830	395	4.55	5.87
8	9	2,240	883	412	2.54	2.40

The variance for columns in the 8-foot plots was only 59% as large as in the 16-foot plots, corresponding to a reduction of 55% in replication length. These results indicate a rather definite relation between the dimensions of the complete square in lattice square designs and the amounts of the total variation removed by rows and columns. It should be pointed out, however, that the error variances of the lattice squares for the two plot shapes and corresponding replication shapes were nearly the same. The error variance when analyzed as a randomized block, however, was considerably higher for the 16-foot plots because of the less compact replication shape. These results would suggest that for yield tests in which varieties may be lost because of adverse conditions short, wide plots would be better suited than long, narrow plots for lattice square designs to reduce the error variance if the test were finally analyzed as a randomized block experiment.

The results from lattice and lattice square designs with 49 varieties is given in Table 5 and for 81 varieties in Table 6. The number of tests that could be made without duplication of plot use was rather limited, but the general results agree very well with those obtained for the 5×5 and 6×6 designs previously discussed. In agreement with results shown in Tables 2 and 3, the gain in precision for 49 varieties in simple and triple lattice designs when the incomplete blocks were arranged in a compact complete replication was considerably less than when arranged in long, narrow strips across the field because of

the lower error variance of the randomized complete blocks. The error variance of the simple and triple lattices, however, were essentially similar regardless of replication shape. The 7×7 and 9×9 lattice square designs gave a considerably lower error variance than the simple or triple lattices indicating, as was shown for the 5×5, that in these studies a considerable portion of the total variance was removed by columns.

TABLE 5.—*Error variance for 49 varieties arranged as 7 × 7 lattice and lattice squares and as randomized complete blocks and the relative precision of the lattice designs for 16- and 8-foot plots.*

Type of design	No. of repli-cates	No. of tests	Shape of replicate, feet	Error mean square		Average relative precision, %
				Lattice design	Randomized blocks	
Center Row of Three-row Plot 16 Feet Long						
Simple lattice	4	3	Compact	645	1,011	156
Triple lattice	3	3	Compact	639	1,051	164*
Lattice square	4	2	21 × 124	489	1,427	293
Simple lattice	4	2	147 × 16	677	1,457	217
Triple lattice	3	3	147 × 16	646	1,424	223*
Center Two Rows of Four-row Plot 8 Feet Long						
Simple lattice	4	4	28 × 68	613	893	144†
Lattice square	4	4	28 × 68	518	893	172†
Simple lattice	4	4	196 × 8	656	1,253	192
Triple lattice	3	6	196 × 8	618	1,220	200*
Triple lattice	3	6	Compact	612	1,110	182*

*Same plots used in both tests.
†Same plots used in both designs.

TABLE 6.—*Error variance for 81 varieties arranged as 9 × 9 lattice and lattice squares and as randomized complete blocks and the relative precision of the lattice designs for 16- and 8-foot plots.*

Type of design	No. of repli-cates	No. of tests	Shape of replicate, feet	Error mean square		Average relative precision, %
				Lattice design	Randomized blocks	
Center Row of Three-row Plot 16 Feet Long						
Simple lattice	4	2	81 × 52	668	1,352	200
Triple lattice	3	3	81 × 52	666	1,301	192
Lattice square	5	2	27 × 160	543	1,561	286
Center Two Rows of Four-row Plot 8 Feet Long						
Simple lattice	4	3	108 × 28	753	1,203	159*
Triple lattice	3	4	108 × 28	723	1,203	163*
Lattice square	5	2	36 × 88	552	1,093	202

*Same total plots used in both designs.

The general summary of all designs given in Table 7 includes the simple and triple lattices arranged in the most compact complete replication to minimize their advantage over the randomized complete blocks. For 25 varieties the five incomplete blocks were in a single series of 25 plots, for 36 varieties in three series of two incomplete blocks, for 49 varieties in two series of two and one series of three incomplete blocks, and for 81 varieties in three series of three blocks each. The above field arrangement was used for both the 8- and 16-foot plots. The field plan for the lattice squares was in conformity to the appropriate arrangement for this design.

TABLE 7.—*Comparison of the error variances of lattice, lattice square, and randomized complete block designs for 25, 36, 49, and 81 varieties and the average relative precision of the lattice designs for 16- and 8-foot plots.*

No. of varieties	Incomplete block designs				Randomized complete block	Average relative precision, %
	Simple lattice	Triple lattice	Lattice square	Average		
Center Row of Three-row Plots 16 Feet Long						
25	673	586	498	586	1,135	194
36	621	618	—	620*	963	155
49	645	639	489	591	1,163	197
81	668	666	543	626	1,405	224
Average	652	627	—	639	1,167	183
Average (excluding 36 varieties)	662	630	510	601	1,234	205
Center Two Rows of Four-row Plots 8 Feet Long						
25	609	586	506	600	990	165
36	612	601	—	607*	965	159
49	613	612	518	581	965	166
81	753	723	552	676	1,166	172
Average	647	631	—	639	1,022	160
Average (excluding 36 varieties)	658	640	525	608	1,040	171

*Not comparable with values for 25, 49, and 81 varieties.

From an examination of the data in Table 7 it is evident that the error variance for the simple lattice was consistently slightly higher than for the triple lattice and that the error variance for the lattice square was lowest in all cases. The variance of the lattice designs was generally somewhat higher as the number of varieties was increased from 25 to 81, with a relatively small change from 25 to 49 varieties.

The variance of the 3×16- and 4×8-foot plots was generally similar except for 81 varieties in the simple and triple lattices. As shown by Zuber (9) and Goulden (4), the shape of the incomplete block itself may influence the variance of these designs, and the sub-block, like the complete replication in a randomized block design, should be arranged in a compact shape. In the 9×9 design of 4×8-foot plots the incomplete block was 8×36 feet in shape, and in the

3×16-foot plots its shape was 16×27 feet. The less compact incomplete block in the 8-foot plots may have contributed to the relatively higher variance in this comparison. From the standpoint of general use in small grain nursery plots there does not appear to be any advantage for the four-row plot 8 feet long over the commonly used rod-row plot. The primary advantage of the shorter plot would be in a saving of total nursery space for yield trials when the border rows are discarded. In the short four-row plots 50% of the plot area would be border row, and in the three-row plot two thirds of the plot would be of borders. The added cost of preparing seed and of planting the short plots probably would offset this advantage in land utilization.

LATTICE AND LATTICE SQUARE DESIGNS IN PLOT TRIALS WITH OATS

For the two-year period 1941–42, 31 lattice and 2 lattice square designs were used in nursery plot trials with oat varieties and selections in the breeding program. In 1941, 7×7 simple lattices with two groups of sets were used in four tests at Ames and three tests at Kanawha. This design was chosen largely because the selections for the yield test were logically grouped into units of this size on the basis of their origin and previous trials. In 1942, the selections grown the previous year were reduced in number and were adapted, in respect to numbers, to 6×6 triple lattice designs. A large number of new selections were also tested for the first time in rod-row plots, and these were also arranged in groups of 36 in triple lattices. With the material on which previous yield data were available two types of plots were used, namely, one set of three-row plots from which the center row was harvested and one of single-row plots. The two lattice square designs were tests of bulk F_2 generation crosses grown in 1941 in three-row plots 8 feet long and bulk F_3 generation from the same crosses grown in 1942 in three-row plots 15 feet long. In both years the center row was harvested for yield.

The relative precision of these designs in comparison with randomized complete blocks as 100 is summarized in Table 8. The 7×7 simple lattices used in the 1941 tests gave, in all cases, an increase in precision over the randomized blocks with a range for both locations of 2 to 55%. The average gains of 30 and 27% for tests at Ames and Kanawha, respectively, are equal to a saving of one replication in four. The 7×7 designs were arranged in a compact replication shape with two blocks in each of two ranges and three blocks in the third range in the nursery.

In 1942, with 16 tests of the 6×6 triple lattice designs in three-row plots, the gain in precision over randomized blocks was relatively small. In six of the 14 tests the variance removed by blocks was less than the variance for error. In these cases the relative precision was determined from the error variance of the randomized block and of the triple lattice without calculating the effective error mean square per plot of the triple lattice. In actual practice, the variance from the randomized block would be used if the triple lattice did not show a gain, but to obtain a valid average for all tests the values of less than

TABLE 8.—*Relative precision of lattice and lattice square designs in comparison with randomized complete blocks in nursery plot trials with oats at Ames and Kanawha, Iowa, 1941–42.*

Design	No. rep-pli-cates	No. tests	Location and year	Plot length, feet	Rows per plot	Relative precision, % Av.	Relative precision, % Range
7 × 7 simple lattice	4	4	Ames, 1941	15	3	130	102–155
7 × 7 simple lattice	4	3	Kanawha, 1941	15	3	127	107–147
6 × 6 triple lattice	3	12	Ames, 1942	15	3	101	91–113
6 × 6 triple lattice	3	4	Kanawha, 1942	15	3	108	96–117
6 × 6 triple lattice	3	4	Ames, 1942	15	1	109	100–120
6 × 6 triple lattice	3	4	Kanawha, 1942	15	1	115	94–152
7 × 7 lattice square	4	1	Ames, 1941	8	3	124	——
7 × 7 lattice square	4	1	Ames, 1942	15	3	100	——
Total or average...		33				111	91–155

100 were included to determine the mean precision for the triple lattice. In the remainder, or eight tests, the triple lattice gave a relative precision of from 100 to 117% with a mean of 101 at Ames and 108 at Kanawha. For the eight tests with single-row plots, the relative precision ranged from 94 to 152% with an average of 109 at Ames and 115 at Kanawha. The somewhat larger gains for the single-row plots was unexpected, because of the smaller area of the complete replication, and may be due to chance in the small number of comparisons in which one gave the large gain of 52%.

In all tests the six blocks were arranged in two ranges of three blocks each to form a very compact, complete replication 54 feet by 34 feet in size for the three-row plots and 18 feet by 34 feet for the single-row plots. This arrangement would be very favorable for a randomized complete block design and would tend to reduce the gain in precision of the triple lattice as shown in Table 2 with the uniformity trial data.

The fields used for the variety trials in 1942 were very uniform both at Ames and Kanawha and definitely superior to those used for the 1941 trials. Growing conditions in respect to rainfall were likewise favorable in 1942, whereas in 1941 an early season dry period tended to differentiate yields in the high and low areas in the nursery. These factors, together with the larger number of varieties per replication in 1941, probably account for the differences in precision from the use of the lattice designs during the 2-year period.

In the two tests with 7×7 lattice squares one gave a gain of 24% and the other no gain over the randomized complete block. In both tests the variance removed by columns was less than that removed by rows, which is in agreement with results shown in Table 4.

Although the average gain in precision for the 33 tests was relatively small, 11%, it is of significance that in several cases the gain was sufficiently large to decrease materially the error variance over that of the randomized blocks and permit an adjustment of the variety means. Since the use of lattice or lattice square designs adds very little to the cost of conducting variety trials, it would seem that

the possibility for increased precision in some tests, and their ready conversion to a randomized complete block analysis when no gains were obtained, would recommend their use for rod-row trials with cereals.

Sufficient data are not available from variety trials to evaluate the relative merits of the types of lattice designs used in this study. From the standpoint of flexibility in arrangement of the blocks, the simple and triple lattices offer definite advantages in nursery plot work, particularly in taking field notes and assembling the selections to permit their consecutive threshing from all replications. The possibility for an arrangement of the blocks to form a compact replication also may be of special value for fall—sown cereals when severe winter killing may necessitate the analysis of the remaining varieties as a randomized complete block experiment. Frequently, the number of replications for large numbers of varieties in lattice squares, especially in preliminary tests, is greater than needed for the precision required to differentiate the selections in respect to yield. These factors have led to the adoption of simple and triple lattice designs in the cereal testing program in connection with small grain breeding at the Iowa Agricultural Experiment Station.

SUMMARY

1. In a uniformity test with oats, 3,942 single-row plots 8 feet in length were combined to form 657 three-row plots 16 feet long and 990 four-row plots 8 feet long. These plots were arranged in different ways to study lattice and lattice square designs assuming 25, 36, 49, and 81 varieties.

2. An arrangement of the blocks in lattice designs to form a compact complete replication reduced the error variance of the randomized complete block but did not materially modify the variance of the lattice design.

3. The mean squares for rows in lattice square designs were higher than for columns in approximately the same ratio as the length and width of the square. The means squares for columns, however, exceeded the error variance.

4. The relative precision of lattice squares exceeded that for triple lattices, and the triple lattice designs were slightly superior to simple lattices. The average precision for the lattice and lattice square designs in comparison with randomized complete blocks as 100 ranged from 155 to 224%.

5. Gains in precision of different sets of a lattice design were in general agreement with variation in soil heterogeneity over the uniformity test plot.

6. The variances of four-row and three-row plots in comparable lattice and lattice square designs were approximately equal.

7. The relative precision of lattice and lattice square designs was also studied in 33 trials with oats varieties and selection.

8. In these variety trials, gains of from 2 to 55% were obtained in 1941 with seven tests using 7×7 simple lattices when compared with randomized complete blocks. In 16 tests in 1942, the 6×6 triple lattice designs with three-row plots varied from a loss of 9% to a gain

of 17% over randomized blocks. Eight tests with single-row plots of this design varied from a loss of 6% to a gain of 52%. In two tests with 7×7 lattice squares one gave no gain and the other a gain of 24%.

9. The adaptation of lattice and lattice square designs to nursery plot trials with small grain was discussed.

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DISINTEGRATION OF CROP RESIDUES AS INFLUENCED BY SUBTILLAGE AND PLOWING[1]

T. M. McCalla and F. L. Duley[2]

THE recent use of crop residues as mulching material for purpose of soil and water conservation (2, 3)[3] has emphasized the need for determining the speed of decomposition of various plant materials when left on the surface of soil as compared with the conventional method of incorporation. As soon as plant residues are returned to the soil, either on the surface or incorporated, they begin to decay. The factors affecting the rapidity of decomposition (7, 8, 9) are (a) the chemical nature of the residues, (b) soil and climatic conditions, and (c) types of microorganisms.

The rate of decomposition of plant residues at the surface of the soil is of direct concern, because the amount of protection the residues afford the land is inversely related to decomposition, while the release of nutrients from plant material is directly proportional to this process. From the standpoint of land protection, plant residues highly resistant to decomposition are most desirable. However, the type of residue available is determined largely by agronomic practice.

The return of crop residues to the surface rather than their direct incorporation into the soil is nature's method of handling residues under all conditions. Plant residues left on the surface of the soil offer better opportunity for aerobic rather than anaerobic decomposition to take place at the soil-residue contact zone. However, the speed of decomposition may be slow. The plant residue mulch as a medium for microorganisms is subjected to rapid fluctuations in temperature and moisture conditions. In the summer, moisture conditions in plant material left on the surface usually remain favorable for microbial activity for only a short time. In the spring and fall the residues at the surface may remain moist a much greater portion of the time. The incorporated residues remain at a more even temperature and are subjected to less rapid drying.

When the mulch is on the surface, the soil does not have much opportunity to supply nutrients to the organisms decomposing the organic material, so they must depend largely upon the plant residues for their nitrogen and other mineral needs. When the plant material is intimately mixed with the soil, the nutrients needed by the organisms may be supplied directly by the soil in case there is an insufficient amount from the decomposing material.

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[3]Figures in parenthesis refer to "Literature Cited", p. 315.

EXPERIMENTAL PROCEDURE

LABORATORY TESTS

A limited amount of work was done in the laboratory on the decomposition of wheat straw (high C-N ratio) and alfalfa tops (low C-N ratio) applied at the surface and incorporated into the soil. Triplicate samples of 100 grams of soil with different residue treatments and rates of application were incubated in glass tumblers at 28° C and maintained at optimum moisture and relative humidity of 80% for 78 days.

FIELD TESTS

Soil samples were obtained from the field experimental plots at Lincoln and Hastings, Nebr., where wheat and oat straw and cornstalk residues in different amounts had been used to test moisture accumulation. The residues were left on the surface of some plots and cultivation done by subsurface tillage. On other plots the residues were plowed under or disked into the surface soil.

METHOD OF ANALYSIS

Laboratory and field samples were analyzed for undecayed organic matter by the method previously described (5). This procedure permits separation of undecomposed or partially decomposed plant material from the soil into three size groups, *viz.*, (a) The plant material retained on a 3-mm sieve was separated by passing the dry soil through a screen, (b) the material less than 3 mm but greater than 0.4 mm was obtained by wet screening of the dispersed soil, and (c) material less than 0.4 mm but which retained its cellular structure was determined by flotation in a tall glass tube where the particles adhered to the walls as the liquid was lowered slowly. These size groups will be designated as 1, 2, and 3 in the order described.

As measured by this method, the plant residue is considered as decayed when it reaches a size slightly less than 0.4 mm. The plant material determined by this procedure is approximately within the macroscopic size range. No attempt is made to measure the amount of organic material in the microscopic or submicroscopic state of subdivision. From general observations in the field, and from limited laboratory studies, it is believed that the material below the macroscopic range is of little importance in acting as a protective covering for the soil.

The amount of plant material found in the control plots was subtracted from the values obtained in the treated plots, and the difference was considered to be the amount remaining from the applied plant material. The weights are given in pounds per acre and are on a 12% moisture basis. The plots were sampled at depths of 0 to 4 and 4 to 8 inches.

RESULTS

LABORATORY TESTS

The importance of the chemical nature of crop residues on decomposition was emphasized by determination of the decomposition rates of plant residues of high and low C-N ratio left on the surface of the soil and incorporated, under controlled optimum moisture and temperature conditions in the laboratory. The wheat straw residue with a high C-N ratio decayed much more slowly when left on the

surface than when incorporated. This reflected the deficiency of the straw in necessary nutrients for microbial needs. As shown in Table 1, the 2 tons of straw on the surface lost 45% of its weight by decay, while the straw incorporated in the soil lost 82% in 78 days.

TABLE 1.—*Decomposition of wheat straw and alfalfa tops when added to soil, under laboratory conditions for 78 days at 28° C, mean of six determinations.*

Organic matter applied	Fragments remaining > 0.4 mm, pounds per acre	Decomposition %
	Straw	
2 tons on surface of soil	2,190	45
4 tons on surface of soil	3,950	51
2 tons mixed with soil	720	82
4 tons mixed with soil	1,150	86
	Alfalfa	
2 tons on surface of soil	1,120	72
4 tons on surface of soil	2,340	71
2 tons mixed with soil	1,080	73
4 tons mixed with soil	2,020	75

With the alfalfa residues (low C-N ratios) retained on the surface, the decomposition was 72%, or approximately the same as when mixed with the soil. Since the alfalfa tops were rich in nitrogen and other mineral nutrients, it was not necessary for the organisms to withdraw nutrients from the soil for the decomposition process. The alfalfa tops left on the surface of the soil were covered with a profuse growth of fungi during the initial stages of decomposition, while on the straw the growth was scant. Albrecht (1) found that sweet clover residues left on the surface of the soil decomposed very rapidly and that by the end of one year no measurable residue was left under field conditions.

FIELD TESTS

Straw-mulched corn land.—In one experiment wheat straw was applied between the rows on plowed corn land immediately after the crop was planted. The rates of application were 0, 2, 4, and 8 tons per acre. In cultivating the corn, broad sweeps were used on the check plot and on the 2- and 4-ton straw-treated plots. The 8-ton treated plot was practically undisturbed, since the straw was heavy enough to hold down weed growth. The amounts of residue left in excess of that of the check plots after 6 months are shown in Table 2 and Fig. 1. The amounts of straw found in the various fractions of the control plot were subtracted from the values obtained in the treated plots in order to obtain the amounts remaining from the applied straw. Finnell (4) reported that after 10 years of continuous fallow in a region of low rainfall, a soil may still contain appreciable amounts of organic matter fragments.

The appearance of the straw residue on the surface after a period of

6 months is shown in Fig. 2. The 2-ton surface application of straw had 6, 19, and 8% of the total in size groups 1, 2, and 3, respectively, or 33% of the original applied material remaining after 6 months. Of the 4-ton surface application of straw, 12, 30, and 9% of fractions 1, 2, and 3, respectively, or a total of 51% of the applied material, remained. Of the 8-ton surface application of straw, the amounts of 52, 16, and 3% of the respective size groups, or a total of 71% of the applied material, remained.

In the size group 1, material greater than 3 mm, the largest amount, 52% of applied material, was found in the 8-ton application, while only 12% of the 4-ton, and 6% of the 2-ton applications remained in this larger size group. Only a small percentage of the material was found in fraction 3 in each treatment. Except for the 8-ton application, more undecomposed or partially decomposed material was found in fraction 2, or the size less than 3 mm and greater than 0.4 mm, than in the other two size groups. This was also true of the residues occurring in the control plot where no straw was added.

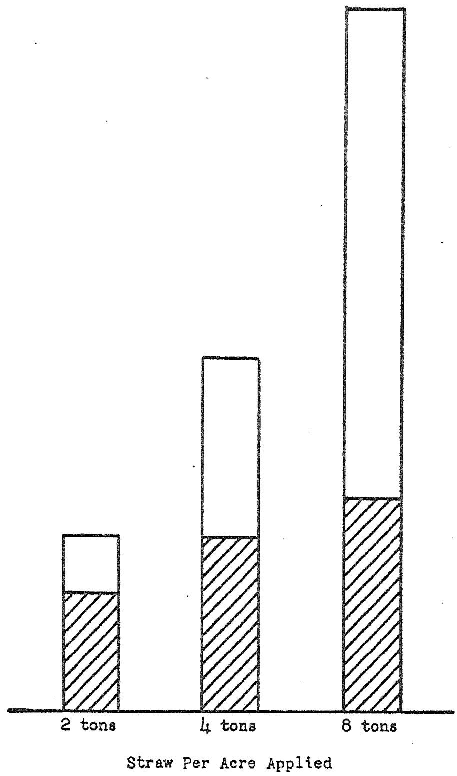

FIG. 1.—Dry matter lost and that remaining from straw applied to corn land, May to November, 1941. Shaded areas indicate dry matter lost by decay in 6 months; open areas, dry matter left in soil.

Summer fallow-wheat land.—In another set of plots used for measuring accumulation of soil moisture, different amounts of wheat straw were applied in April 1940. These were fallowed for 6 months and then seeded to wheat. By the end of 18 months all but 7% of the straw residue had disappeared, regardless of the rate of application, as shown in Table 3. These results show that the applied straw had lost by decay most of its protective value as a mulch on all plots, except the 8-ton application. However, the effects of the organic decomposition products may have definite physical and chemical effects on the soil (6).

Rotation plots.—Where oats and wheat residues were returned in a

TABLE 2.—*Pounds per acre of undecomposed straw and percentage of original application on an area basis in different separates remaining 6 months after application to corn land, mean of triplicate plots, sampled 0–4 inches.*

Treatment	Size groups			
	>3 mm	3 mm–0.4 mm	<0.4 mm	Total
No straw (check)	189	1,542	453	2,184*
2 tons of straw	425	2,282	767	3,474
Increase over check†	236	740	314	1,290
% remaining of original straw	6	19	8	33
4 tons of straw	1,151	3,925	1,204	6,280
Increase over check	962	2,383	751	4,096
% remaining of original straw	12	30	9	51
8 tons of straw	8,429	4,104	917	13,450
Increase over check	8,240	2,562	464	11,266
% remaining of original straw	52	16	3	71

*The error in the method of determination ranges from approximately 200 to 400 pounds per acre.

†No straw (check) subtracted from total to eliminate effect of organic material already in the soil.

TABLE 3.—*Pounds per acre of straw residues remaining after 18 months on plots fallowed for 6 months, followed by wheat, samples 0–4 inches.*

Treatment	Size groups				Increase over check, lbs.	Residue per ton applied, lbs.
	>3 mm	3 mm–0.4 mm	<0.4 mm	Total		
No straw	154	1,184	770	2,108	—	—
Disked, 2 tons of straw	137	1,260	682	2,080	−28	−14
Subtilled, 2 tons of straw	57	1,567	735	2,361	253	126
Subtilled, 4 tons of straw	52	1,714	905	2,672	564	141
Subtilled, 8 tons of straw	102	2,054	1,201	3,359	1,251	156

rotation of oats, wheat, and corn, samples taken in December 1941 following corn showed that the plowed plots contained 1.0, 0.2, and 3.6% of material remaining in size groups 1, 2, and 3, respectively (Table 4). This was one year after the wheat residue and two years after the oats residue had been added. The plots with the residue left at the surface showed 1.6, 23.2, and 11.6% of the applied residue in the respective groups remaining at the end of this 2-year period. The total of the three fractions showed only 4.8% of applied straw remaining in the three size groups where the residue was plowed under, and 36.4% of the wheat and oats residue remained where they were subtilled and left on the surface. On the plowed plot the added material had disappeared to a point where the amount of macroscopic material remaining was similar to that found in the control plot. In the mulched plot there was a marked accumulation of fine material,

largely in the upper 1 to 2 inches of the soil where it could be seen with the eye on examination of the soil in the field.

Summer fallow with cornstalk mulch.—Cornstalks were applied on the surface to field plots and the land fallowed for 6 months, May to September 1941. At the end of this period 44.5, 19.6, and 6.9% in fractions 1, 2, and 3, respectively, or a total of 71.1% of the applied

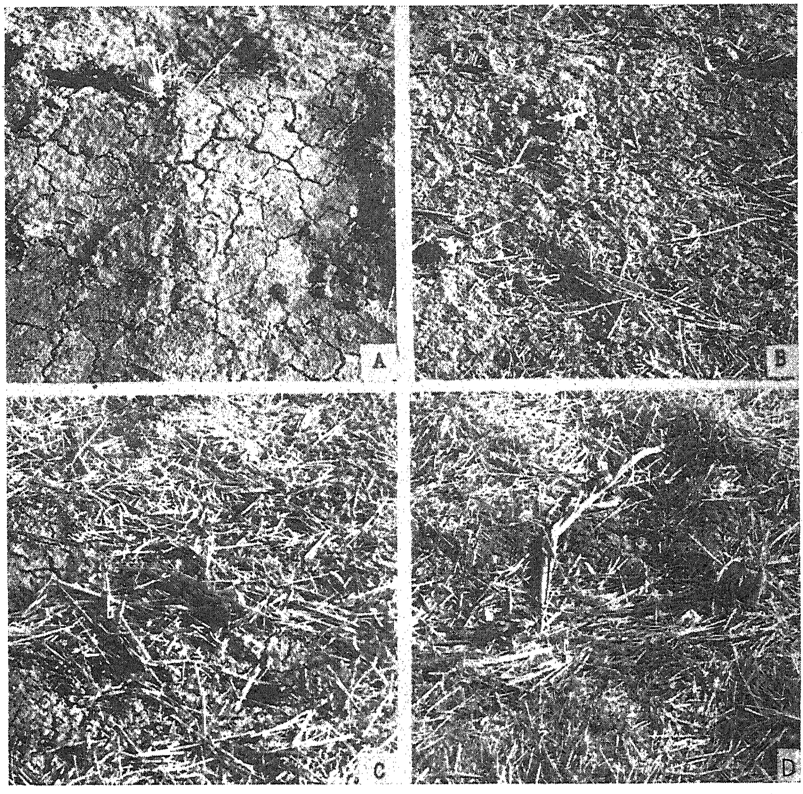

FIG. 2.—The appearance of wheat straw residues November 1941, 6 months after application of, A, no straw; B, 2 tons; C, 4 tons; and D, 8 tons of straw per acre applied on surface.

residues, remained. Cornstalks were applied to other plots the previous year, May 1940, and the land was fallowed for 6 months. This land was then in wheat and stubble for 12 months. At the end of 18 months after application, only 3.2, 12.6, and 1.2% of the applied material remained in fractions 1, 2, and 3, respectively, or a total of 17%. These data are shown in Table 5 and the appearance of a plot in Fig. 3.

Continuous corn.—Land in corn for two successive years, with the residues returned to the surface each year, was compared with land where the stalks were plowed under. The results show an accumula-

TABLE 4.—*Pounds per acre of organic particles and percentage of applied material remaining in corn land where residues of oats and wheat had been returned in a rotation of oats, wheat, and corn; mean of triplicate samples from each of three plots.*

Treatment	Depth, inches	Size groups			
		>3 mm	3 mm–0.4 mm	<0.4 mm	Total
No straw, plowed	0–4	55	1,307	451	1,813
	4–8	20	753	482	1,255
Total		75	2,060	933	3,068
Straw, plowed*	0–4	87	1,344	631	2,062
	4–8	55	732	527	1,314
Total		142	2,076	1,158	3,376
Increase over no treatment	—	67	16	225	308
% remaining of original straw	—	1.0	0.2	3.6	4.8
Straw, subtilled*	0–4	125	2,781	1,061	3,967
	4–8	50	698	580	1,328
Total		175	3,479	1,641	5,295
Increase over no treatment	—	100	1,419	708	2,227
% remaining of original straw	—	1.6	23.2	11.6	36.4

*Total residue added during period, 6,100 pounds of straw per acre.

TABLE 5.—*Pounds per acre of cornstalk material and percentage of original application remaining in the soil 6 and 18 months after surface application, mean of 6 plots, sampled 0–4 inches.*

Treatment	Size groups			
	>3 mm	3 mm–0.4 mm	<0.4 mm	Total
After 6 Months				
Cornstalks, 2 tons per acre	1,855	2,156	861	4,872
None (check)	73	1,372	584	2,029
Difference	1,782	784	277	2,843
% of applied material left in soil after 6 months	44.5	19.6	6.9	71.1
After 18 Months				
Cornstalks, 2 tons per acre	282	1,690	821	2,793
None	154	1,184	770	2,108
Difference	128	506	51	685
% of applied material left in soil after 18 months	3.2	12.6	1.2	17.0

tion of raw organic matter in the subtilled plots over the plowed plots of 20.9, 9.8, and 3.3% for fractions 1, 2, 3, respectively, one year after the last addition of stalks (Table 6). Where the cornstalks were left

on the surface, the land was cultivated by means of sweeps that passed through the soil under the residues. Cornstalks left on the surface decayed very slowly. When cornstalks were completely covered with fertile, moist soil, they decayed rather rapidly. Stalks buried for a

FIG. 3.—Cornstalk residues remaining after 18 months on plots fallowed for 6 months by subsurface tillage followed by wheat.

6-weeks period in the early spring showed a profuse growth of fungi, and most of the pith, sheaths, and leaves had disappeared.

DISCUSSION

When straw or cornstalks were left on the surface of the soil, they remained undecayed for a longer time than when they were incor-

TABLE 6.—*Pounds per acre of undecomposed plant material and percentage of original application remaining from a total of 2.5 tons of cornstalks applied during a 2-year period, the last application being made 1 year prior to sampling.*

Treatment	Depth, inches	Size groups			
		>3 mm	3 mm–0.4 mm	<0.4 mm	Total
Subtilled	0–4	1,137	2,194	627	3,958
	4–8	119	686	346	1,151
Total		1,256	2,880	973	5,109
Plowed	0–4	164	1,403	482	2,049
	4–8	44	985	327	1,356
Total		209	2,388	809	3,405
Difference		1,047	492	164	1,703
% of applied material left in soil as result of subtillage in excess of plowing		20.9	9.8	3.3	34.1

porated. From these results it is evident that the greatest surface protection to the soil for the longest time can be obtained by cultivating in such a manner as to avoid mixing of the plant residues into the soil. However, if the nutrients locked up in the plant material are needed by the growing crop, their delivery by microbial decomposition can be hastened by incorporating the residues with the soil.

The results of the laboratory experiment indicated that longer soil protection may be obtained by using a crop residue deficient as a diet for the microorganisms, thus resulting in slower decay. It would seem possible to lengthen this period of protection against runoff and soil erosion by the development and use of crop residues with a high lignin content, or having other components which are highly resistant to decomposition, or having ratios of chemical components which disfavor growth of microorganisms.

SUMMARY

Measurements of plant residue fragments in the soil of macroscopic size showed approximately 1 ton of plant residue fragments in the upper 4 inches of normal cultivated soil at Lincoln, Nebr. More than one-half of this amount of plant residue fragments was found in the size group of less than 3 mm and greater than 0.4 mm. Since these soils contained about 40 tons of organic matter per acre, these organic matter fragments constitute only 2.5% of the total organic material of the soil.

When alfalfa tops and wheat straw were left at the surface of soil in pot cultures, maintained under controlled moisture and temperature conditions, the alfalfa tops decayed far more rapidly than did the straw.

When straw was used as a mulch for a period of 6 months, the 2-ton application had lost two thirds; the 4-ton, one half; and the 8-ton, one third of the added material. Where straw was left on the surface for 18 months, there was little residue left except from the 8-ton application.

When 2 tons of cornstalks were applied to the surface, about two thirds of the material was left after 6 months. Some cornstalk residue was left after a period of 18 months. From these data it appears that cornstalks are more resistant to decay than straw.

The weight of organic particles remaining in corn land where oats and wheat straw from the two previous crops had been returned was 2,227 pounds where left on the surface and only 308 pounds per acre where the residues were plowed under.

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THE EFFECT OF TEMPERATURE ON SEED SET IN BARLEY CROSSES[1]

Harry V. Harlan, Mary L. Martini, and Harland Stevens[2]

THE data analyzed in this paper were not obtained from an experiment designed to show the effect of temperature on seed set. The figures used were incidental in a breeding project in the execution of which 12,028 flowers were emasculated and 9,932 seed obtained. The procedure was modified from day to day in any way which, in the judgment of the writers, would obtain the greatest number of seed under the prevailing weather conditions. To make a conclusive study of the effect of temperature, an equal number of flowers should be handled at all intervals at several temperatures under controlled conditions. Since no one is likely ever to emasculate 12,000 barley flowers for such a study, any analysis that can be made of other crossing programs seems worthwhile, even if they suffer from faulty design and required liberal interpretation.

The writers had all made barley crosses for many years. The percentage of seed set was almost the same regardless of who made the emasculations or pollinations.

A record of the operations for each spike used was kept and included the day, hour, and minute of emasculation and of pollination. The temperatures were obtained from a thermograph. The data were transferred to punch cards and classified on a Holworth machine.

A general picture of the situation is shown in Fig 1. Here the temperatures shown are the ones that occurred at the moment of pollination. Since most of the pollinations were done before noon, the daily maximums are scarcely indicated. The curve of percentage of set suggests a negative correlation with temperature at the time of pollination. The writers had felt that there was some dropping off of seed obtained from pollinations late in the day. However, one must remember that these temperatures are of necessity correlated with the daily maximum and, as will be shown later, such maxima are even more strongly correlated with emasculation injuries. When these are considered the writers could not establish any significant relation between set and temperature at pollination time. When the operations of single days were considered, some did and some did not show decreases during the day. If an effect is present, it is small.

The effect of temperature on emasculation is indicated in Fig. 2. Here only the total failures are recorded, i.e., spikes in which no seed set. Total failures are usually due to damage suffered in emasculation. We have pollinated flowers when it was so cold our hands were numb. We have pollinated them under umbrellas during rainstorms. We have even sponged free water out of the flowers with bits of

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cotton. Yet our total failures are largely limited to periods of hot weather during which some spikes blasted after emasculation and in many others the peduncle ceased to elongate. During such periods it is practically impossible to use certain varieties, such as Everest, as female parents, because the pollen ripens when the peduncle and glumes are hardly more than stiff jelly.

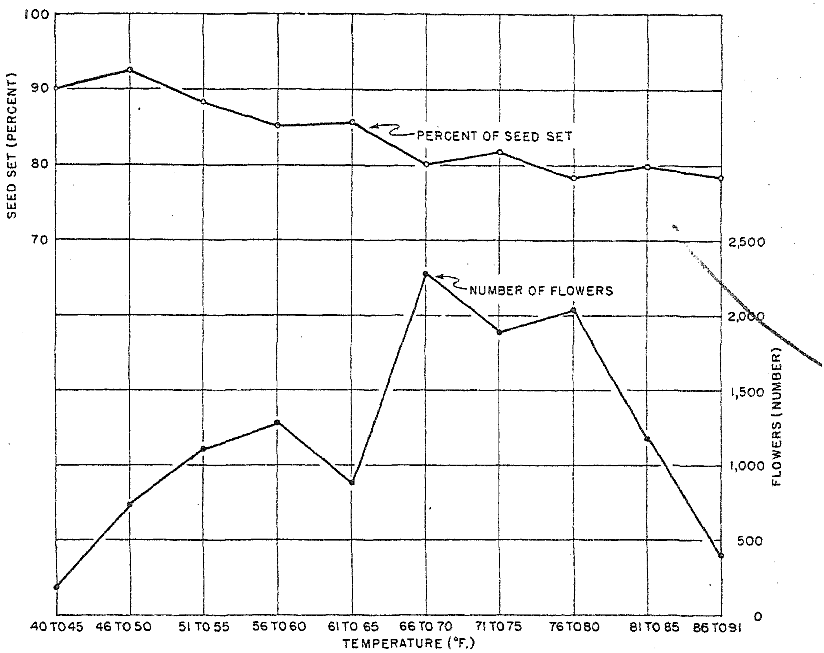

FIG. 1.—The effect of temperature on seed set in barley crosses.

The effect of continuous hot weather is shown in Table 1. Here the data for all 12,028 flowers are analyzed by correlating the percentage of set with both the maximum and minimum temperatures for the day of emasculation and for each of 6 previous days. It had been the experience of the writers that continued hot weather was a major factor in emasculation damage, but the length of the cumulative period was not known.

It is difficult to get all the "bugs" out of these figures. For instance, the minimum temperatures go along with the maximum ones, most probably because they are correlated with them. Again, excessively hot days do not immediately succeed cool ones but usually build up so that part of the effect in days 0 and 1 are cumulative effects that are overstressed when considered separately. Also, with 17 classes a correlation of around 0.5 is necessary to be significant. Despite these handicaps the surprising uniformity of the minus values for 5 days preceding emasculation is convincing. They are particularly convincing to the writers because they already knew they had plenty of

TABLE I.—*Correlation coefficients, percentage of seed set and maximum and minimum temperature, day of emasculation to 6 days before emasculation.*

Item	Days before emasculation						
	0	1	2	3	4	5	6
% seed set and maximum temperature	−.76	−.64	−.52	−.65	−.61	−.47	−.12
% seed set and minimum temperature	−.40	−.46	−.53	−.47	−.33	−.07	+.04

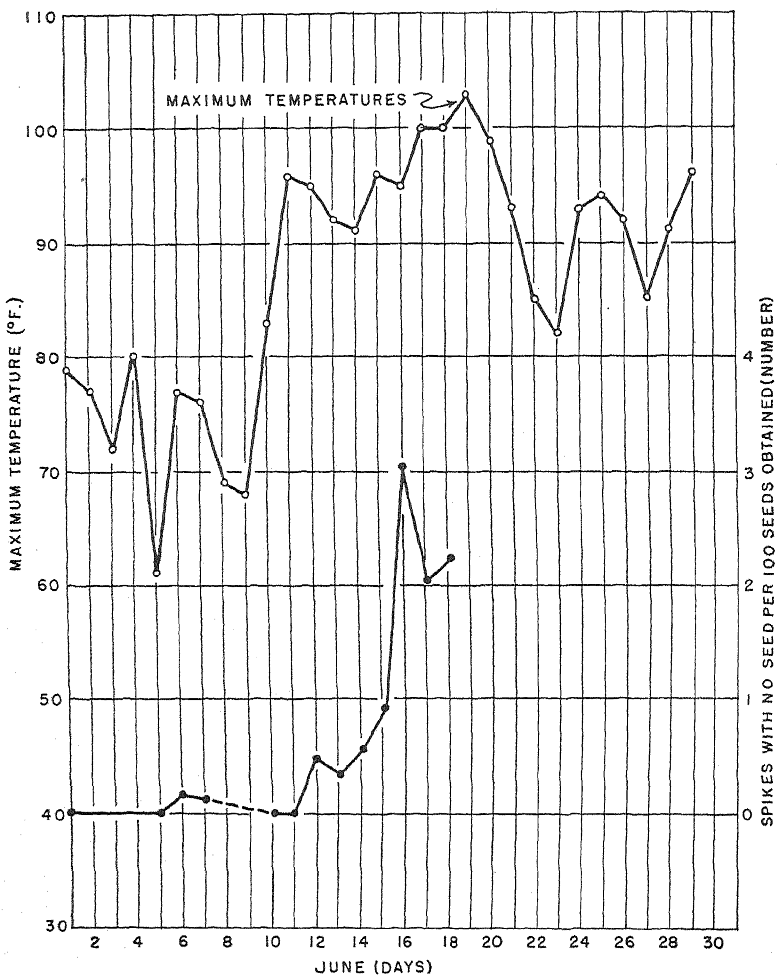

FIG. 2.—The effect of temperature on emasculation in barley crosses.

trouble in hot weather. The figures in Table 1 indicate that the temperature of the 5 days preceding emasculation have a decided bearing on the seed set of a cross.

DISCUSSION

The normal story of the crossing season at Aberdeen is about as follows: The early varieties flower in cool days with maximum temperatures in the 60's or low 70's. Emasculation in all cases is done at the latest stage when danger of free pollen is not yet present. The stamens in the early plants can be safely removed after the spikes are partly exserted. The flowers do not open for 2 or 3 days after emasculation. Pollination can be delayed for 4 or 5 days; everything sets.

Under Aberdeen conditions crossed seed usually develop well, and for over half the season would be classified as plump barley. A random sample of several hundred crossed seed gave a kernel weight of 32.5 mgs, which is good barley. The later seed is usually not so plump. At Sacaton, Ariz., where late-season crosses are made in very hot weather, the kernel weight of such crosses is low, often at the border line of germination.

Manchuria, when used as a female parent at Sacaton, exhibits the entire series of results. Crosses made early on Manchuria set nearly 100% of seed and produce large kernels. The peduncles continue to elongate after emasculation and the culms bearing emasculated spikes are nearly or quite full height. As the weather gets warmer the set decreases slightly, the culms do not elongate as much, and the seed is smaller but usable. In extremely hot weather the seed set is further reduced, blighted spikes become common, and often the peduncle does not grow after emasculation. The seed often does not develop more than a few days and is frequently too small to use. Many winter varieties are as bad or worse than Manchuria. Sometimes seed cannot be obtained at all for several days at a time. It was discovered that sets could be obtained by putting wet cotton in the bags beside the spike at pollinating time. This discovery is useless, however, because on spikes injured enough to require such treatment the seed never developed far enough to be useful for field planting.

Barleys of the Coast group can be worked much more successfully in hot weather. The damage is less, the percentage of seed set greater, and the resulting kernels larger.

Later in the season at Aberdeen the maximum temperatures are in the low 80's. The spike is enclosed in the upper leaf at emasculation time. The peduncle is still firm and the operation not difficult. The flowers open about 2 days after emasculation. Hot days with a maximum of 90° to 100° soon follow. The first day or two make little difference. The peduncles are still firm and the spike not difficult to unwrap. The flowers, however, are ready to pollinate 1 day after emasculation. If hot weather continues, the pollen ripens earlier and earlier with reference to the peduncle and the glumes. It is often necessary to unwrap the second leaf and support the spike until the unwanted flowers are removed and the awns clipped off. The reduced spike will support itself. Most flowers open in 24 hours. Failures of

entire spikes begin to be numerous. The seed, when obtained, is often undersized. If the program eventually necessitates the utilization of secondary culms, the difficulties are further increased. They are more difficult to work and set less seed than primary ones.

During this time another change has taken place. In the early season the flowers on a spike are all near the same stage of development and an entire spike can be emasculated if desired. As hot weather comes on some of the central flowers are ready to emasculate when those above and below and the lateral flowers are undeveloped. Only a part of the flowers can be used when the spikes are in this condition. Immature flowers, if emasculated, usually dry up in hot weather.

SUMMARY

Within the temperature ranges occurring at Aberdeen, Idaho, the success of crosses in barley is little affected by temperature at pollinating time. Pollen is more difficult to find as the day advances during hot weather.

The interval between emasculation and pollination is 2 days under average temperature conditions. Better sets are secured if this interval is lengthened to 3 days in the very early season and shortened to 1 day in the hottest weather.

The effect of high temperatures on the success of emasculations is considerable. During long-continued heat the pollen ripens at earlier and earlier stages in the development of the spike, necessitating the manipulation of spikes so tender that injuries are common. There is an increase in total failures, a decrease in the percentage of seed set, and a reduction in the size of the kernels obtained. High temperatures show a significant negative correlation with seed set for 5 days before emasculation.

CROP RESPONSE TO HORMONE SEED TREATMENTS[1]

T. A. KIESSELBACH[2]

HORMONE dust treatments for the seed of farm crops are now recommended and offered for sale by their manufacturers.[3] Various alleged benefits are quicker, stronger, and higher percentage germination; improved stands; stronger root systems; more rapid plant growth; superior resistance to adverse climatic factors; greater plant size; substantially increased yields of forage and grain; hastening of maturity; help in fighting drouth, erosion, wind damage, and other plant enemies, actually providing drouth insurance; all obtained at low cost per acre.

Early in 1942 the press[4] called public attention to hormone seed treatment results obtained with various crops by J. C. Ireland of the Oklahoma Agricultural Experiment Station and interpreted by him as evidence of highly beneficial crop effects. Consequently it was considered advisable to investigate the possibilities of the hormone-seed treatment of farm crops in Nebraska, such tests being made in 1942 and herewith reported.

The crops under study were oats, barley, soybeans, and corn. The corn included an open-pollinated variety, first and second generations of hybrid U. S. 13, and an inbred line known as Ind. 38–11. The hormone seed treatments included five standard synthetic hormones commonly considered in such research and two commercial hormone dusts, all applied at several dosages.

The tests were conducted on the Agronomy Farm at Lincoln, Nebr., using standard crop production practices. The soil is tentatively classed as Marshall silty clay loam but has a heavier and more compact subsoil than is typical for that soil type. It has a pH of 5.7. The season was sufficiently drouthy to curtail distinctly the yield of the crops involved.

LITERATURE REVIEW

Published results concerning the effect of hormone seed treatments upon crop yields under field conditions are rather meagre.

McRostie, Hopkins, and Grace (6)[5] report the 1938 winter wheat responses at the Ontario Agricultural College, Guelph, Canada, to various concentrations of indolyl acetic and naphthylacetic acids applied to the seed in the form of dusts. This was a triplicate paired-experiment of split-plot design, comparing directly treated and untreated seed of each of two varieties. Ten treatments and 10 varieties were involved, utilizing 60 nursery plots split lengthwise and measuring 18½ feet by 10 rows wide. Whereas the average grain yield of all plots was 48.5 bushels

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[2]Agronomist.

[3]A. E. Staley Mfg. Company and Jean Maclean and Associates.

[4]Omaha World Herald, January 4, 1942.

[5]Figures in parenthesis refer to "Literature Cited", p. 331.

per acre, there was a mean significant increase of 1.25 bushels, or 2.6%, for all hormone applications. The maximum significant increase in the grain yield of any variety was 6.8 bushels, or 13%, and the maximum significant reduction in yield was 5.95 bushels. The authors concluded that there was a rather striking differential response of varieties to hormone seed treatment, based on a number of statistically significant differences such as a gain of 5.9 bushels grain for Red Rock wheat and a loss of 5.95 bushels for the Dawbul variety in response to an application of 100 p.p.m. of naphthylacetic acid.

The effects of treating the seed of 24 species with various growth substances was studied by Barton (2) at Boyce Thompson Institute. The tests pertained primarily to germination and seedling growth, although some plants were grown to maturity. Inclusive dosage ranges were tested for napthaleneacetic acid solution soaking treatments and also for powder treatments with Auxan, Rootone, and Merk preparations containing indole butyric acid. No stimulating effects were found either as to speed or percentage of germination. No species exhibited accelerated seedling growth when grown in soil. Stunting effects from some of the higher concentrations were noted with some species. Seed treatment failed to affect the growth rate and time of maturity of wheat, oats, spring rye, meadow fescue, perennial rye grass, and Kentucky bluegrass.

Youden (8) conducted replicated greenhouse and field tests at Boyce Thompson Institute with soybeans and wheat, measuring the respective effects of seed treatment with wide ranges of application of indole acetic acid, naphthaleneacetic acid, indole butyric acid, talc, and Rootone (commercial preparation) upon germination, seedling height, and yield of roots, tops, and grain. He concluded that, "No significant case was found in which the germination and growth of the treated lots exceeded the controls. . . . . On the average the excess weight of the control plants was about 5%." The lower values of the treated lots were attributed to the presence of the talc which was used as the base for powder preparations.

Templeman and Marmoy (7) report detailed observations on the effects of seed treatment with various dust concentrations of naphthylacetic acid and indolyl acetic acid. "These have not stimulated the germination, tillering, growth in height or dry matter production of oats, barley, sugar beets or wheat grown in sand and soil in pot cultures, and of wheat and oats in small scale field experiments."

Dexter (3), in a nursery test with sugar beets replicated five times at the Michigan Agricultural Experiment Station in 1941, studied the effect of seed treatment with four different hormones (indole acetic acid, naphthaleneacetic acid, indole butyric acid, and phenylacetic acid) at various concentrations in water solution in comparison with water-soaked and dried water-soaked seed as controls. One or the other of the controls surpassed all of the hormone-treated seed in respect to yield of beets per acre, percentage of sugar, and yield of sugar per acre.

J. C. Ireland (4, 5) has reported various crop responses to hormone seed treatment tests made at the Oklahoma Agricultural Experiment Station. Responses to soaking seed 4 hours in a 0.1% hormone solution were as follows: Naphthaleneacetic acid increased the yield of soybeans 57%, White Darso (grain sorghum) 58%, stock beets 54%, and alfalfa 27%. Corresponding increases for levulinic acid were soybeans 47%, darso 8%, stock beets 145%, and alfalfa 39%. The technic of the experiments and statistical significance of the results were not indicated. From studies with hybrid corn, Ireland concluded that the high-yielding hybrids contain an unusual amount of indole propionic acid. Quoting him (5,

page 4), "It was assumed that a substitution of a similar material into the plant would produce similar results, and this has been the case. The question arises, 'Is it better as a plant breeder to select strains of corn which naturally contain the growth substances that lead to higher yields and greater vigor, or is it advisable to introduce the substance into ordinary corn and obtain similar results?' In actual practice we find that the latter is much quicker than the long methods which we have followed of obtaining pure lines."

In a recent article, Auchter (1) lists among important practical achievements in agricultural research, the use by orchardists of growth-regulating substances (plant hormones) as sprays to prevent "fruit drop" by apple trees. He also refers to the constructive use of hormones in causing plant cuttings to root more rapidly; but makes no mention of the use of hormones as seed treatment.

EXPERIMENTAL PROCEDURE

PLOT TECHNIC

In order that the results of a single season might be fairly indicative of crop responses to be expected from hormone seed treatments in this region, tests were laid out with thorough plot technic involving 8 to 10 replications. The crops were grown by standard production practices. Rather full agronomic observations were made on the growing and mature crop.

Corn.—The corn plots consisted of three rows 10 hills long planted at a double rate and thinned at random in the seedling stage to two plants per hill. The plots were randomized in 10 replicate blocks. Yields of both stover and grain were calculated on a 15% moisture basis. The entire crop of ear corn from the middle row of each plot was artificially dried and shelled for yield determination. All plots under comparison were harvested on the same day, soon after maturity.

Soybeans.—The soybean plots consisted of three 50-foot rows spaced 40 inches and having the seed dropped at 2-inch intervals. Randomization in 10 replicate blocks was followed. Yields of grain and straw were calculated on a 15% moisture basis from the entire product of the center rows after artificial drying.

Oats and barley.—Performance of each crop was based on eight randomized replications of three-row nursery plots sown at the rate of 2 bushels of seed per acre. The middle rows, 16 feet in length, were harvested for yield.

MANNER OF SEED TREATMENT

The hormones under test as water solutions were levulinic acid, indole acetic acid, indole butyric acid, phenylacetic acid, and naphthaleneacetic acid. These chemically pure materials were obtained from the Eastman Kodak Company. Where made necessary by low solubility, the materials were dissolved in minimal volumes of ethyl alcohol before diluting with water to the desired concentrations. Three concentrations were studied for each hormone, except naphthaleneacetic acid for which five were used. Application was by soaking the seed in the solution for a period of 8 hours at 72° F, followed by draining and planting. These hormone solutions were tested exclusively with an open-pollinated variety of corn. The average amount of solution absorbed was 245 grams per 500 grams of air-dry seed. The soaked seed averaged 43% moisture content.

Two commercial hormone dust treatments, GrainO and Staymone, were tested. The active principle of Staymone is stated by its manufacturers to be levulinic acid, while GrainO is said to contain propionic acid and other growth

TABLE 1.—*Effect of various hormone seed treatments on the growth and yield of open-pollinated corn (Hays Golden variety), Lincoln, Nebr.**

Concentration, p.p.m.	Seedling emergence		Seedling weight, age 2 weeks (moisture free), grams	Plant height, inches		No. of days to 70% shedding pollen	No. of plants per plot harvested Oct. 2†	Moisture in ear corn, %	Shelled corn, %	Yield per acre (15% moisture)	
	After planting, days	Age 2 weeks, %		Age 4 weeks	Mature					Stover, lbs.	Grain, bu.‡
					Levulinic Acid						
Control§	5	82.5	0.71	27.3	74	62	18.8	47	80	2,675	32.4
100	5	83.3	0.73	26.0	74	62	19.0	48	81	2,675	33.2
50	5	81.9	0.68	26.9	76	62	18.8	47	80	2,717	31.4
10	5	81.2	0.72	26.1	76	62	17.8	47	81	2,508	30.1
					Indole Acetic Acid						
100	5	80.0	0.60	26.5	76	62	19.1	45	80	2,495	31.9
50	5	82.0	0.72	27.0	75	62	18.8	45	80	2,508	32.9
10	5	79.6	0.71	27.1	76	62	19.4	46	81	2,533	33.0
					Indole Butyric Acid						
Control§	5	80.1	0.67	27.0	76	62	18.2	46	81	2,587	31.2
100	5	81.8	0.60	26.7	75	62	18.1	47	81	2,424	30.6
50	5	81.3	0.64	27.9	76	62	18.0	46	80	2,679	30.3
10	5	79.9	0.61	26.6	77	62	18.5	47	81	2,675	31.8
					Phenylacetic Acid						
100	5	79.1	0.67	26.8	76	62	18.7	47	81	2,516	31.9
50	5	77.6	0.68	27.0	74	62	18.3	47	81	2,495	31.8
10	5	79.0	0.67	27.7	76	62	18.7	46	80	2,533	32.2

Naphthaleneacetic Acid											
Control§	5	83.1	0.63	26.6	75	62	18.7	47	81	2,508	31.6
1,000	8	40.1	0.26	19.2	72	67	12.2	53	76	1,760	15.3
500	7	62.8	0.33	22.8	74	64	16.7	50	79	2,479	24.9
100	5	76.7	0.62	25.9	75	62	18.5	47	80	2,571	31.7
50	5	83.6	0.67	27.3	76	62	18.0	46	80	2,554	32.0
10	5	82.9	0.66	26.4	76	62	18.4	47	80	2,675	31.5
GrainO											
Control**	6	82.3	0.56	25.5	77	62	18.5	47	80	2,672	32.2
0.5††	6	80.8	0.57	24.9	77	62	18.3	47	80	2,587	31.3
2.0	6	82.8	0.54	25.2	76	62	19.1	48	80	2,591	32.3
4.0	6	83.9	0.53	25.0	76	62	18.5	48	80	2,586	31.1
Staymone											
Control**	6	80.0	0.52	25.2	77	62	18.0	47	80	2,692	32.0
0.5††	6	81.8	0.61	25.7	76	62	18.5	47	80	2,642	31.3
2.0	6	83.2	0.59	25.6	75	62	18.9	46	79	2,625	32.7
4.0	6	80.1	0.58	26.1	77	62	18.8	47	80	2,583	32.5

*Data based on middle rows of three-row plots 10 hills long and replicated 10 times. Plots planted at double rate, later thinned to two plants per hill. Water solutions applied by soaking seed 8 hours. Dusts applied to seed by thorough dusting.

†Twenty plants represent a perfect stand.

‡Difference necessary for significance 2.0 bushels.

§Three controls planted to identical water-soaked seed.

**Two controls from identical untreated seed.

††Ounces per bushel of seed.

substances proved successful or superior. Application to the seed was by means of 30 revolutions of a small seed duster. Both dusts were tested in conjunction with open-pollinated corn, F_1 and F_2 hybrid corn, inbred corn, and soybeans. GrainO only was used on oats and barley.

RESULTS

OPEN-POLLINATED CORN

The five chemically pure hormones under study were tested uniformly on open-pollinated corn at three distinct concentrations in water solutions, some one or more of which might be expected to prove a suitable dosage. Two additional, more concentrated solutions of one of these hormones, naphthaleneacetic acid, were included so as to test a wider range of treatment. The two commercial hormone dusts were each applied at three rates which were within the range recommended by their manufacturers.

FIG. 1.—View of Hays Golden corn field testing hormone seed treatments. Photographed 6 weeks after planting, 1942. Left, control, seed water-soaked 8 hours; right, seed soaked 8 hours in 0.01% water solution of phenylacetic acid.

As controls for measuring the effect of the hormone solutions, three identical water-soaked entries were included in the series of 28 entries which constituted the experiment (Fig. 1). Two untreated dry controls were entered for comparison with the dry dust treatments.

The yields and other agronomic data are included in Tables 1 and 2. A statistical analysis of the grain yields shows that a difference of 2.0 bushels between treatments is necessary for significance at the 5% level.

None of the treatments gave a significantly higher yield than the controls nor otherwise favorably affected the germination, field stand, or vegetative development of the crop. The two most concentrated solutions of naphthaleneacetic acid, *viz.*, 500 and 1,000 p.p.m., proved very harmful and yielded 24.9 and 15.3 bushels per acre, respectively, compared with 31.7 bushels as an average for the three water-soaked controls. These excessive treatments also materially curtailed the percentage seedling emergence, early seedling growth rate, and stover yield, and resulted in delayed maturity,

TABLE 2.—*Summary of grain yields in bushels per acre (15% moisture) of open-pollinated corn (Hays Golden) from seed treated respectively with three concentrations each of five different pure synthetic hormones in water solution as compiled from Table 1, 1942.**

Hormone	Hormone in water solution, p.p.m.				
	None†	100	50	10	Av.
Control No. 1	32.4	—	—	—	—
Levulinic acid	—	33.2	31.4	30.7	31.8
Indole acetic acid	—	31.9	32.9	33.0	32.6
Control No. 2	31.2	—	—	—	—
Indole butyric acid	—	30.6	30.3	31.8	30.9
Phenylacetic acid	—	31.9	31.8	32.2	32.0
Control No. 3	31.6	—	—	—	—
Naphthaleneacetic acid	—	31.7	32.0	31.5	31.7
Averages	31.7	31.9	31.7	31.7	31.8

*Difference necessary for significance 2.0 bushels. Seed soaked 8 hours with 10 replications.
†The three controls were planted from identical, water-soaked seed.

higher moisture content of ear corn when husked, and lower shelling percentage. The 0.1% solution especially provided an inferior stand of distinctly reddish colored seedlings which developed more slowly throughout the season. The surviving plants from this excessive treatment were individually inferior to those of the control, yielding only 72% as much grain per plant. The plants grown from seed treated with the 0.05% solution were also inferior, yielding only 87% as much, individually, as the controls.

HYBRID AND INBRED CORN

A comparative study was made of the response to hormone seed treatment by various classes of corn differing in degree of hybrid vigor, *viz.*, open-pollinated, F_1 hybrid, F_2 hybrid, and inbred. All were grown in the same field and environment, but were handled in three distinct randomized blocks. Each kind of corn was tested with both GrainO and Staymone applied at the recommended rate of 2 ounces per bushel of seed.

In the case of the open-pollinated variety (Table 1), there were no significant differences in grain yield or vegetative development as a result of these 2-ounce dust treatments. The data indicate a 0.2 bushel increased yield for GrainO and 0.6 bushel increase for Staymone.

Rather typical differences in yield were obtained between the F_1 and F_2 hybrids and the inbred line (Table 3), their respective relative grain yields being 100, 71, and 24%. These differences, involving hybrid vigor, are highly significant. However, no significant gain in the grain yield of any lot resulted from hormone treatment. There is indication that 2 ounces of Staymone (a 1% levulinic acid dust) was somewhat excessive for both the F_2 and inbred seed. Their grain yields were both significantly lowered by this treatment.

The seedling emergence was distinctly low for the Staymone and somewhat so for the GrainO treatment of hybrid and inbred seed,

TABLE 3.—*Effect of commercial hormone dust seed treatments on the growth and yield of U. S. 13 F_1 and F_2 hybrids and Ind. 38–11 inbred corn.**

Treatment†	Seedling emergence: After planting, days	Seedling emergence: Age 2 weeks, %	Seedling weight, age 2 weeks (moisture free), grams	Plant height, inches: Age 4 weeks	Plant height, inches: Mature	No. of days to 70% shedding pollen	No. of plants per plot harvested Oct. 2‡	Shelled corn, %	Yield per acre (15% moisture): Stover, lbs.	Yield per acre (15% moisture): Grain, bu.§
F_1 Hybrid										
Control	5	91	0.57	28.2	101	79	19.2	82	3,234	36.4
GrainO	5	83	0.55	27.1	100	79	18.2	82	3,108	35.1
Staymone	5	76	0.59	27.9	102	79	18.1	81	3,234	36.4
F_2 Hybrid										
Control	5	90	0.45	26.6	95	81	19.8	81	2,772	27.6
GrainO	5	89	0.46	25.4	93	81	19.1	80	2,730	26.8
Staymone	5	75	0.43	24.4	93	81	17.7	80	2,646	24.5
Inbred Line										
Control	6	78	0.26	15.9	73	87	18.8	74	1,922	8.8
GrainO	6	74	0.27	17.2	72	87	18.6	73	1,780	8.0
Staymone	7	60	0.24	15.2	72	87	15.0	69	1,495	6.1

*Data based on middle rows of three-row plots 10 hills long and replicated 10 times. Plots planted at double rate; later thinned to two plants per hill.
†Controls had no seed treatment. The dusts were applied at 2 ounces per bushel.
‡Twenty plants represent a perfect stand.
§Difference necessary for significance 2.95 bushels for hybrids and 1.01 bushels for inbred.

suggesting sensitivity thereto. These data in no way add credence to an hypothesis that open-pollinated varieties may be made as productive as superior hybrids through hormone seed treatment.

TIME OF PLANTING CORN

The effect of treating seed with commercial hormone dusts in connection with the time of planting was observed with Reid Yellow Dent corn. Planted at the normal date, May 15, the untreated control yielded 27.0 bushels per acre compared with 26.4 and 25.3 bushels for GrainO and Staymone, respectively, applied at 2 ounces per bushel of seed. Planted late, June 15, the corresponding three yields were control, 19.5 bushels; GrainO, 18.9 bushels; and Staymone, 19.5 bushels per acre. These yield differences were not significant. The official mean and maximum air temperatures during the week following each planting date were May 15 to 21, 57° and 77° F, and June 15 to 21, 68° and 89° F.

SOYBEANS

Scioto soybeans treated respectively with GrainO and Staymone at the rate of 2 ounces per bushel of seed, yielded 15.1 bushels and 14.9 bushels per acre (Table 4) compared with 15.0 bushels for the control. The slight differences between treatments are not significant. There were no material effects upon the stand, vegetative development, or yield of soybeans.

TABLE 4.—*Effect of commercial hormone dust seed treatments upon the growth and yield of Scioto soybeans, 1942.**

Treatment	Dust per bushel of seed, ounces	Time for seedling emergence, days	No. of plants per 10 feet of row	Plant height, inches		Date ripe	Yield per acre	
				Age 4 weeks	Mature		Total grain and straw, lbs.	Grain, bu.†
Control	None	7	55	6.6	28.6	Sept. 26	3,434	15.0
GrainO	2	7	57	6.9	28.6	Sept. 26	3,478	15.1
Staymone	2	7	53	6.5	28.3	Sept. 26	3,362	14.9

*Data based on middle rows of three-row plots 50 feet long replicated 10 times.
†Difference necessary for significance 0.85 bushel.

OATS AND BARLEY

These two small grain crops were given a seed treatment only with GrainO at the application rates of 0.5, 1.0, 2.0, and 3.0 ounces per bushel of seed. The two controls received no treatment. No dosage of GrainO caused either crop to surpass the control (Tables 5 and 6) in yield of grain. Neither was there a significant reduction. There

TABLE 5.—*Effect of a commercial hormone dust (GrainO) seed treatment applied at four rates per bushel upon the growth and yield of Otoe oats, 1942.**

Treatment	Dust per bushel of seed, ounces	Seedling emergence after 6 days, %	Date ripe	Plant height, inches	Test weight of grain, lbs.	Yield per acre	
						Total grain and straw, lbs.	Grain, bu.†
Control	No	50	July 10	33	26	4,931	35.5
GrainO	0.5	45	July 10	33	26	4,666	34.0
GrainO	1.0	44	July 10	33	26	4,861	35.1
Control	No	55	July 10	33	27	4,702	36.7
GrainO	2.0	46	July 10	33	25	4,643	34.3
GrainO	3.0	41	July 10	33	26	4,541	34.6
Av. 2 controls	——	53	July 10	33	27	4,817	36.1
Av. GrainO	——	44	July 10	33	26	4,678	34.5

*Data based on middle rows of three-row plots 16 feet long replicated eight times. Drilled 2 bushels of seed per acre.
†Difference necessary for significance 3.7 bushels.

were no other appreciable agronomic effects, except that seedling emergence was slightly retarded by the treatment. Ultimate stands were estimated to be equally good and no growth differences were noted.

TABLE 6.—*Effect of a commercial hormone dust (GrainO) seed treatment applied at four rates per bushel upon the growth and yield of Spartan barley, 1942.**

Treatment	Dust per bushel of seed, ounces	Seedling emergence after 6 days, %	Date ripe	Plant height, inches	Test weight of grain, lbs.	Yield per acre	
						Total grain and straw, lbs.	Grain, bu.†
Control.......	No	41	July 9	27	46	4,188	30.1
GrainO.......	0.5	30	July 9	28	45	4,168	27.6
GrainO.......	1.0	32	July 9	28	46	3,933	27.0
Control.......	No	37	July 9	28	45	4,064	27.8
GrainO.......	2.0	28	July 9	28	46	4,121	28.0
GrainO.......	3.0	32	July 9	28	46	4,162	28.5
Av. 2 controls	—	39	July 9	28	46	4,126	29.0
Av. GrainO...	—	31	July 9	28	46	4,096	28.0

*Data based on middle rows of three-row plots 16 feet long replicated eight times. Drilled 2 bushels seed per acre.
†Difference necessary for significance 4.4 bushels.

SUMMARY AND CONCLUSIONS

No significant benefits as to germination, seedling development, maturity, or yield were derived from any hormone seed treatment applied to open-pollinated corn, F_1 hybrid corn, F_2 hybrid corn, inbred corn, soybeans, oats, and barley.

The two strongest naphthaleneacetic acid treatments (0.1 and 0.05% solutions) were distinctly toxic and harmful, curtailing germination, growth, and yield.

Seed treatment with 100, 50, and 10 p.p.m. solutions of five respective hormones gave essentially equal results, and without superiority over the controls. This suggests that the use of still more dilute hormone solutions would not have altered the results.

The commercial hormone dusts applied to the seed did not result in crop performance superior to that of the untreated controls or of the three more dilute hormone solutions.

Hormone seed treatment in no way served to offset the comparatively low hybrid vigor of an open-pollinated variety, F_2 hybrid, or an inbred line, and gave no evidence that such treatment could raise the productivity to the level of an F_1 hybrid. There was no more tendency for favorable response by an ordinary variety of corn than by a standard first-generation hybrid.

Judged by the outcome of these investigations and those reported in the literature, no hormone seed treatment can be recommended in Nebraska for any farm crop.

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RUNOFF FROM PASTURE LAND AS AFFECTED BY SOIL TREATMENT AND GRAZING MANAGEMENT AND ITS RELATIONSHIP TO BOTANICAL AND CHEMICAL COMPOSITION AND SHEEP PRODUCTION[1]

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THIS paper presents results of soil treatment and grazing management studies conducted for 4 years at the Dixon Springs Soil and Water Conservation Experiment Station in Pope County, Ill. The station is in the lower Mississippi loess area, typical of many millions of acres in the Ohio and Mississippi Valleys. The results are applicable to this large area. Hilly land which has been devoted to the production of cultivated crops is badly eroded. A system of farming which makes extensive use of pastures appears to be the best possibility of maintaining much of the area in profitable agricultural production. Land used for these studies is a part of a larger acreage purchased by the federal government for a pasture experiment station. Both the Illinois Agricultural Experiment Station and the Soil Conservation Service have studies underway, the results of which will be of assistance in solving the agronomic and livestock production problems of the area.

The project reported herein was one of the first to be placed in operation on the area. The purpose of the experiment is to determine the effect of intense and moderate grazing and of different soil treatments on soil and water losses and on the forage production of permanent pasture. Yearly soil and water losses under the various treatments are reported. The production of the various plots is reported as total forage yields, botanical composition of vegetation, chemical composition of forage, and weight of sheep.

METHODS

The design of the experiment, treatment, and technics of measurement were described briefly in an earlier paper (1).[3]

Yearling ewes grazed the areas during the seasons of 1938 through 1941. Yearling ewes were not available in 1942; therefore, ewes with one lamb were used. Records have been maintained both of days of grazing and of gains or losses in weight of sheep. Intensively pastured plots were grazed severely throughout the season. The sheep on plots where grazing was regulated were handled so that vegetation was maintained at a minimum height of about 3 inches.

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[1]This study is being conducted as a cooperative project between the Illinois Agricultural Experiment Station, Urbana, Ill., and the Soil Conservation Service, Office of Research, U. S. Dept. of Agriculture. Also presented at the annual meeting of the Society in St. Louis, Mo., November 11, 1942. Received for publication January 6, 1943.

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[3]Figures in parenthesis refer to "Literature Cited", p. 347.

The method for obtaining forage yields was revised in 1940. Prior to 1940 five protected areas and five unprotected areas were sampled in each ⅓ acre plot. In 1940 and subsequently, five pairs of wire-cage enclosures, 3 feet 4 inches on each side, were located at random on each plot. From one of each pair of cages, hay samples were harvested and separated into the various forage plant species represented. From the second one of each pair of cages, samples were harvested at intervals of 30 to 45 days throughout the season. Height at which forage was cut from these latter cages varied according to the method of grazing used on the particular plot. The severely grazed plot samples were cut closely or about 1 inch from the ground, while the moderately grazed plot samples were cut at a height of approximately 3 inches. Yields of forage in all cases were calculated as pounds per acre of oven-dry forage.

The study is replicated on two sites on the area. Replicate one, consisting of ⅓-acre grazing units, plots 1 through 5, was treated and seeded in the fall of 1936. One runoff plot 70×14 feet in size was constructed within each grazing plot, except plot 3–4 on which two runoff plots were located. Grazing was started on all units of replicate one in the summer of 1938. Replicate two was treated and seeded in the fall of 1938. However, since a uniformity test indicated undesirable soil variation on the plots, the ⅓-acre areas of replicate two, plots 6 through 9, were divided into ⅙-acre units, and one half of each plot was connected to one half of an adjacent plot with similar soil treatment to constitute a ⅓-acre grazing unit. This was done in the summer of 1941. Two runoff plots, 70×14 feet in size, were located on each ⅓-acre grazing unit of replicate two. Since these latter plots have been in operation for only a short period of time, most of the results reported herein, except the chemical analyses, were secured from replicate one, plots 1 through 5, which has been in operation since 1938.

Soil treatments on the treated plots consisted of 3½ tons of limestone, 1,000 pounds of rock phosphate, and 300 pounds of 32% superphosphate per acre. Additonal applications of 150 pounds of 20% superphosphate were made to the treated plots of replicate one in the spring of 1939 and to the treated plots of replicate two in 1941.

DISCUSSION OF RESULTS

RUNOFF

The application of limestone and phosphate and the use of regulated grazing reduced runoff during the 4-year period, July, 1938, through June, 1942. Runoff from plot 2, treated and moderately grazed, was only 3.4% of the total precipitation of 140.10 inches for the period (Table 1).

Soil treatment alone did not reduce runoff. It was necessary to practice controlled grazing even on treated plots. On the severely grazed areas, plot 1, treated, lost more water than plots 3 and 4, untreated. Although the differences in runoff between plot 1 and 3 and 4 were small, the greater runoff from plot 1 may be explained by the composition of vegetation on these specific plots. Plot 1, treated and severely grazed, contained desirable grasses and legumes that were consumed early in the season, and were not available later to prevent runoff, while plots 3 and 4, untreated contained high percentages of weeds that were not readily consumed by sheep. This weed growth was partially effective in reducing runoff, but not as effective as the

TABLE 1.—*Soil loss and percentage of runoff from plots as influenced by soil treatment and grazing management July 1938 to June 1942.**

Year	Rainfall, inches	Plot No. 1	2	3	4	5
		Soil Loss, Lbs. Per Acre				
1938†.........	16.82	630	51	232	490	344
1939‡.........	23.91	1,030	80	300	887	217
1940..........	38.66	504	52	122	310	226
1941..........	33.95	778	58	79	178	150
1942§.........	26.76	602	98	193	403	525
Total.........	140.10	3,544	339	926	2,268	1,462
		Runoff, %				
1938†.........	16.82	6.5	1.1	8.8	15.7	12.8
1939‡.........	23.91	21.2	3.7	10.1	17.5	12.8
1940..........	38.66	16.8	2.1	7.3	11.0	11.8
1941..........	33.95	14.5	1.9	7.5	10.2	14.3
1942§.........	26.76	24.9	8.6	13.4	26.2	29.0
Total.........	140.10	17.3	3.4	9.2	15.4	16.0

*Plot 1, treated and severely grazed; plot 2, treated and moderately grazed; plot 3–4, untreated and severely grazed; plot 5, untreated, moderately grazed.
†July through December, 1938.
‡April through December, 1939.
§January through June, 1942.

more palatable forage produced and partially retained on plot 2, treated and moderately grazed.

Runoff is less and infiltration of rainfall is greater on treated, moderately grazed land than on untreated, severely grazed land. Increased infiltration creates a greater potential supply of ground water for forage production. A high infiltration capacity is especially important on treated, moderately grazed areas, as improved pastures maintain dense stands of vigorous plants that require much moisture for growth and transpiration. In many years, periods of drought occur during midsummer. During such periods, the differences in runoff from individual storms between poor and good pastures are greater than the yearly differences reported in Table 1 (Fig. 1).

Differences obtained from a rain of 4.02 inches on July 3 and 4, 1941, are an excellent example of what may be expected during drought periods. On treated plots, one third of this rainfall, or 1.45 inches, was lost as runoff from plot 1, severely grazed, while only about one twenty-fifth, or 0.17 inch, of the rainfall was lost from plot 2, moderately grazed. Previous to the rain of July 3 and 4, transpiration and utilization of soil moisture by the good forage on plot 2 had reduced the moisture in the soil on this plot more than on the severely grazed plot. Increased infiltration from this one storm replenished the supply of soil moisture which remained higher on plot 2 than on plot 1 for at least 5 days following the storm. The

moisture content of the soil in percentage of total weight of sample 4 days before and 5 days after the rain of July 3 and 4, 1941, was as follows:

Treatment	Surface 6 inches		Subsurface 6–12 inches	
	4 days before, %	5 days after, %	4 days before, %	5 days after, %
Plot 1, treated, severely grazed....	5.64	14.09	11.58	16.35
Plot 2, treated, moderately grazed	3.63	16.03	8.13	17.02

SOIL LOSSES

Soil losses for the 4-year period July, 1938, through June, 1942, are presented in Table 1. Soil losses from all plots have been low. This fact emphasizes the value of permanent cover in controlling erosion. Plot 1, treated and severely grazed, has lost more soil than any of the other plots. At the present rate of loss on plot 1, 300 years would be required to erode 1 inch of surface soil from this plot. The authors recognize that soil losses from these plots probably are smaller than would be obtained under farm pasture conditions. The slope length of the plots is fixed at 70 feet, while the length of slopes in pastures is usually longer and would permit concentration of water in waterways, which if improperly protected, might develop into gullies.

The possible advantages of soil treatment and moderate grazing in controlling erosion are indicated by the runoff obtained from the plots. On the treated plots the amount of water lost from plot 1, severely grazed, was five times the amount from plot 2, moderately grazed. A reduction of runoff of this magnitude as a result of management practices should be very effective in controlling soil losses on large watersheds.

FORAGE YIELDS

The amounts of various plant constituents in samples of hay which were taken from protected areas within each grazing unit are reported as pounds per acre in Table 2. Close grazing on both treated and untreated land increased the amount of weeds, and at the same time decreased the amounts of redtop, lespedeza, and other desirable grasses and legumes (Fig. 2). Likewise, considerably more weeds were present on the untreated plots than on the treated plots irrespective of the grazing management that was followed. The yield of hay from these plots after removal of weeds averaged approximately ¼ ton per acre on untreated land as compared to about 1 ton per acre on treated land with regulated grazing.

During the 4 years of record, the amount of Kentucky bluegrass in the hay samples on plot 2, treated, moderately grazed, increased from 250 pounds per acre in 1940 to 850 pounds in 1942. Very little bluegrass was present on the untreated plots 3–4 and 5.

The amounts of redtop in the hay samples decreased on the plots regardless of soil treatment and grazing management; however, the seasonal yields of redtop on the plot treated and moderately grazed were many times greater than on the untreated, severely grazed plot.

Lespedeza or other desirable legumes should be present on an improved pasture in this area to supply a palatable forage for livestock production during late summer and early fall. Although additional seedings of lespedeza have been made, lespedeza yields have been unsatisfactory, except where the plot was treated and carefully

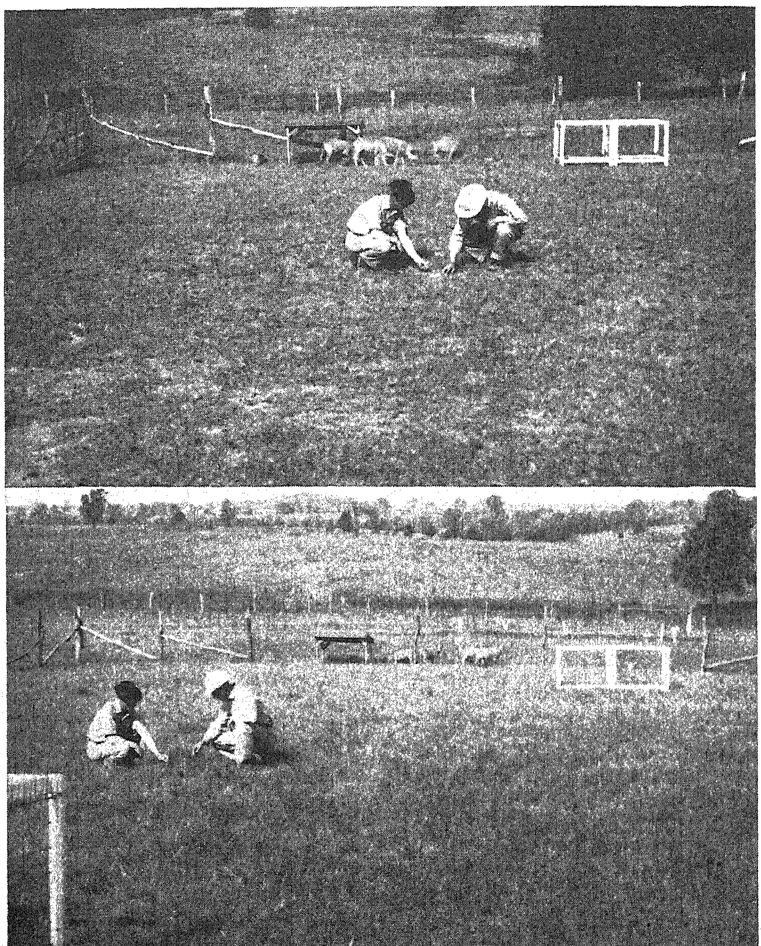

FIG. 1.—Effect of grazing management on vegetative cover which is available for protection against runoff. Above, severely grazed plot which lost 1.45 inches of water during a storm in July in which 4.02 inches of rain fell. Below, moderately grazed plot which lost only 0.17 inch during the same storm.

grazed. In 1942, as a result of an exceptionally favorable growing season, lespedeza yields were satisfactory on all plots, but production

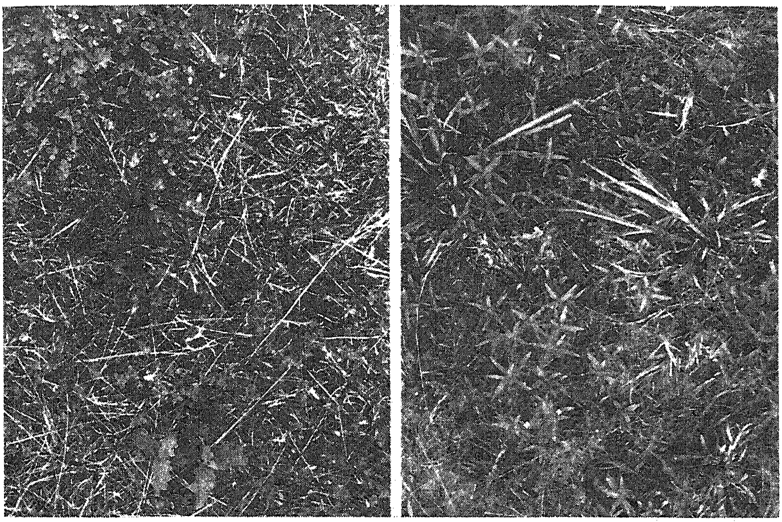

FIG. 2.—Soil treatment and moderate grazing reduces weeds and increases desirable vegetation. Left, plot 3–4, closely grazed and untreated; right, plot 2, moderately grazed and treated.

TABLE 2.—*Yearly yields of each species in hay samples from protected areas as influenced by soil treatment and previous grazing management, 1940–42.*

Plot No.*	Cover, pounds per acre						
	Kentucky bluegrass	Red-top	Lespedeza	Sweet clover	Other species	Weeds	Total grasses and legumes
			1940				
1	262	542	217	0	114	726	1,135
2	250	1,248	709	0	458	111	2,665
3–4	2	433	56	0	55	1,695	546
5	0	447	120	0	0	939	567
			1941				
1	763	374	179	0	193	786	1,509
2	534	1,042	680	0	207	245	2,463
3–4	22	34	45	0	9	2,602	110
5	9	437	70	0	9	1,760	525
			1942 (First Cutting)				
1	90	34	929	553	25	435	1,631
2	850	331	1,656	99	11	117	2,947
3–4	22	4	589	0	0	1,616	615
5	0	50	787	0	0	1,202	837

*Plot 1, treated and severely grazed; plot 2, treated and moderately grazed; plot 3–4, untreated and severely grazed; plot 5, untreated and moderately grazed.

was greater on plots receiving soil treatment and good grazing management.

SHEEP PRODUCTION

The number of days of grazing with sheep and the gains or losses in weight from the various plots are shown in Table 3. Although some variation in gains or losses in weight of sheep occurred as a result of seasonal variation, obvious differences between plots resulted from soil treatment and grazing management.

TABLE 3.—*Sheep gains or losses and pasture days of grazing Dixon Springs Soil and Water Conservation Experiment Station, 1939–42.**

Plot No.	Treatment	Year 1938	1939	1940	1941	1942	Av., 1939–42
	Pasture Days Per Acre						
1	Lime, phosphate, intensively grazed	1005	606	642	591	888	682
2	Lime, phosphate, regulated grazing	498	594	438	591	834	614
3, 4	No soil treatment, intensively grazed	675	546	390	402	756	524
5	No soil treatment, regulated grazing	249	336	162	210	447	289
	Gains or Losses in Weight of Sheep, Lbs. Per Acre						
1	Lime, phosphate, intensively grazed	—	+ 27	+ 75	− 72	+ 18	+ 12
2	Lime, phosphate, regulated grazing	—	+204	+114	+126	+132	+144
3, 4	No soil treatment, intensively grazed	—	− 39	− 12	− 48	+ 54	− 11
5	No soil treatment, regulated grazing	—	+ 63	+ 60	+ 24	+123	+ 68

*A pasture day refers to the pasturing of one yearling ewe for one day.

During 1939 treated plots, Nos. 1 and 2, were comparable to each other in composition of stand and amounts of available forage for livestock consumption. Likewise the two untreated plots, Nos. 3–4 and 5, compared favorably with each other. Two to three times as many days pasturage were obtained from the severely grazed plots during the first season, 1938, as from the moderately grazed plots. During the 4-year period, 1939 through 1942, a severely grazed condition was obtained on treated land from an average annual increase of only 22 pasture days. This increase represented 11% more pasture days from severely grazed than from moderately grazed plots. On the severely grazed pasture, plot 1, sheep gained only 12 pounds per acre annually. On plot 2, with good grazing management, sheep gained at an average rate of 144 pounds per acre. Assuming a value of 10 cents per pound for sheep, the gross annual return from the moderately grazed, treated pasture was $14.40 per acre, while the gross return from the severely grazed pasture was only $1.20 per acre. This is an annual difference on treated land of $13.20 in favor of the pasture which had been grazed in a manner to promote the growth of desirable vegetation. The authors realize that most farmers would not graze their pastures so heavily that unfavorable returns would be experienced yearly. However, such management does exist on some farms where the condition of livestock is not considered important,

providing they are obtaining a bare subsistence ration. Overstocking of the plots in this experiment resulted in a low quality of forage and in small gains by livestock.

On untreated land, controlled grazing was also effective in increasing livestock production. The sheep on plot 3–4, severely grazed, lost 11 pounds per acre, while the sheep on plot 5, moderately grazed, produced an average annual gain of 68 pounds per acre. Assuming again that sheep are worth 10 cents per pound, the average annual gross return from the properly grazed pasture was $6.80, while the loss on the over-grazed pasture was $1.10. This is a difference of $7.90 in favor of the plot on which grazing was regulated.

Assuming limestone delivered and spread on the field to be worth $2.00 per ton, 20% superphosphate at $27.00 per ton delivered to the farm, and rock phosphate at $14.00 per ton, the total cost of treatment would be approximately $24.00 per acre. When management and soil treatment are considered collectively, the increase in gross returns per acre is $15.50. This increased return per acre was obtained with only slightly increased cost, as the average number of pasture days for the 4-year period, 1939 through 1940, was 614 days per acre on the treated plot with regulated grazing and 524 days per acre on the plot which was untreated and severely grazed. If $3.50 per acre annually is allowed for increased cost of production because of slightly increased numbers of sheep per acre on treated land, the soil treatment would pay for itself in a 2-year period.

BOTANICAL COMPOSITION OF STANDS

Botanical composition of the forage stands on plots 1 to 5 as determined by vertical point quadrat readings are presented in Tables 4 and 5. Table 4 shows the yearly composition of stands for all species except lespedeza in April of each year during the period 1938–42. Stands of lespedeza on the various plots in the fall are included in the table. The plots were grazed for the first time shortly after the measurements were taken in April, 1938. Measurements taken on five dates during the 1941 grazing season are shown in Table 5. This table shows the change in composition during the season.

The seeding mixtures and rate of seeding in pounds per acre which were used in the fall of 1936 and the spring of 1937 were as follows: Fall 1936, orchard grass, 5 pounds; Kentucky bluegrass, 2½ pounds; redtop, 4 pounds; timothy, 2 pounds; sweet clover, 2 pounds; alsike clover, 1½ pounds. Spring, 1937, white clover, 2 pounds; sweet clover, 3 pounds; Korean lespedeza, 5 pounds. Each year in early spring, except in 1940, an additional seeding of 5 pounds of lespedeza per acre was added.

The effect of closeness of grazing and of soil treatment on each of the species is discussed below.

Kentucky bluegrass.—A soil treatment consisting of limestone and phosphate appears to be the first requirement for establishment of Kentucky bluegrass. Bluegrass constituted a large proportion of the vegetation on the treated plots for the past three seasons, while the amount of bluegrass on untreated plots was negligible. These results

TABLE 4.—*Average percentage of cover by various species at Dixon Springs Soil Conservation Experiment Station, 1937–42.*

Plot No.*	Percentage of pasture cover					
	1937 Nov. 18	1938 Apr. 12	1939 Apr. 26	1940 Apr. 29	1941 Apr. 17	1942 Apr. 20
			Kentucky Bluegrass			
1	2	4	9	23	36	28
2	2	6	13	27	39	52
3–4	1	1	4	4	3	1
5	1	1	2	1	1	1
			Redtop			
1	7	11	17	21	9	1
2	13	10	21	33	23	12
3–4	6	22	18	4	5	0
5	12	21	19	15	10	6
			Timothy			
1	15	28	13	3	2	0
2	13	33	15	11	0	0
3–4	2	7	2	0	0	0
5	7	12	4	0	0	0
			Orchard Grass			
1	18	11	8	0	0	0
2	21	15	11	3	3	0
3–4	15	10	1	0	0	0
5	6	5	0	0	0	0
			Total Grasses			
1	42	54	47	47	47	29
2	49	64	60	74	65	64
3–4	24	40	25	8	8	1
5	26	39	25	16	11	7
			White Clover			
1	1	0	1	0	0	0
2	1	3	1	0	1	0
3–4	0	0	0	0	0	0
5	0	0	0	0	0	0
			Lespedeza			
1	2	3	1	7	6	34
2	3	38	33	20	25	53
3–4	0	0	2	6	7	15
5	0	6	5	7	14	44

*Plot 1, treated and severely grazed; plot 2, treated and moderately grazed; plot 3–4, untreated and severely grazed; plot 5, untreated and moderately grazed.

confirm the findings of other workers (2, 3) who have reported that Kentucky bluegrass under favorable soil conditions persists well in competition with other grasses. On the treated plots, bluegrass was more prevalent on the moderately grazed plot than on the severely grazed plot. It increased until in the spring of 1942 it represented

52% of the cover under moderate grazing and 28% under severe grazing. These increases were made under conditions which eliminated orchard grass and timothy from the stands. Kentucky bluegrass was most prevalent on the treated plots during the spring, early summer, and late fall. On the basis of these results, which are confirmed by other observations and experiments on the station, Kentucky bluegrass is the most desirable permanent pasture grass for a continuous cover in the area.

TABLE 5.—*Composition of stands by vertical point quadrat during 1941 grazing season, Dixon Springs Soil Conservation Experiment Station.**

Date	Kentucky bluegrass, %	Redtop, %	Lespedeza, %	Weeds, %	No vegetation, %	Dead vegetation, %
			Plot 1			
Apr. 17	36	9	0	4	22	27
June 10	16	4	5	32	17	25
July 23	13	0	5	58	15	9
Sept. 26	5	0	6	51	17	21
Oct. 29	13	1	0	11	11	64
			Plot 2			
Apr. 17	39	23	3	3	5	23
June 10	32	11	19	9	5	22
July 23	22	6	17	13	9	31
Sept. 26	34	3	25	13	6	19
Oct. 29	44	10	5	3	8	27
			Plot 3, 4			
Apr. 17	3	5	0	10	13	69
June 10	3	3	7	65	3	19
July 23	0	0	6	75	6	13
Sept. 26	0	0	7	60	2	31
Oct. 29	1	0	0	10	1	88
			Plot 5			
Apr. 17	1	10	0	13	18	58
June 10	0	10	7	55	2	26
July 23	0	4	7	59	12	18
Sept. 26	0	2	14	46	13	25
Oct. 29	1	4	4	16	11	64

*Plot 1, limestone, phosphate, severe grazing; plot 2, limestone, phosphorus, moderate grazing; plot 3–4, no soil treatment, severe grazing; plot 5, no soil treatment, moderate grazing.

Orchard grass and timothy.—The frequency of occurrence of orchard grass and timothy in 1938 was high; however, the incidence of both species declined rapidly in subsequent years. On the untreated plots in 1939, the orchard grass was relatively an unimportant constituent of the stand. By the spring of 1940, only traces of orchard grass occurred even on the treated plots. Timothy responded to soil treatment and to regulated grazing more than orchard grass as indicated by the frequency of occurrence of timothy on plot 2, treated and moderately grazed, during the period 1938–40. However, only traces of timothy remained on the plots in 1941. These results indicate that on treated

land orchard grass and timothy may be used in pasture mixtures to furnish pasturage while bluegrass is becoming established. The longevity of orchard grass and timothy, however, will be limited even when protected by moderate grazing.

Redtop.—On untreated land, the percentage of redtop has been higher than the percentage of any other grass, and it has persisted longer. The results confirm the fact that redtop is the best grass available for pasturage on untreated soils of low productive capacity. On treated soils, redtop does not occur on the plots as frequently as Kentucky bluegrass, and it is more adversely affected by severe grazing than is Kentucky bluegrass. However, redtop is preferred to orchard grass or timothy in permanent pasture seedings in southern Illinois to furnish desirable cover during establishment of Kentucky bluegrass.

White clover and sweet clover.—Only insignificant quantities of white clover have appeared on the treated plots and none on the untreated plots. Only a few sweet clover plants appeared in the stand from the original seedings. An additional seeding was made on all plots in the spring of 1942.

Korean lespedeza.—The frequency of occurrence of lespedeza plants on the various plots has varied with soil treatment and grazing management. Close grazing reduced the frequency of appearance of lespedeza. Lack of limestone and phosphate also adversely affected the stand. The treated plot with regulated grazing was the only plot that consistently maintained a stand of lespedeza to provide satisfactory grazing during summer months. Although annual spring seedings were made, except in 1940, the frequency of lespedeza was low on the untreated plots even with moderate grazing until 1942, during which season the rainfall was usually high and well distributed. In a pasture cover made up of a mixture of grasses and legumes, where grasses supply the spring pasture and lespedeza the summer and fall pasture, lespedeza is easily destroyed in the seedling stage by close grazing.

Weeds.—Weeds were much more prevalent on the severely grazed than on the moderately grazed plots (Fig. 2). They were also more prevalent on the untreated than on the treated plots. On the treated, moderately grazed plot, weeds constituted only a small percentage of the vegetation, while on the severely grazed and untreated plots, weeds accounted for about 50% of the vegetation during the summer months. The most prevalent weeds were *Aristida gracilis*, *Andropogon virginicus*, and *Diodia teres*. None of these weeds can be eliminated by close grazing.

PROTEIN AND PHOSPHORUS ANALYSES

Forage composition analyses for crude protein and phosphorus content were started in the fall of 1939. Analyses of composite samples obtained at that time and again in the early summer of 1940 are shown in Table 6.

A number of factors may influence chemical composition, namely, botanical composition, soil type, soil treatment, climate, and grazing management. The effects of botanical composition on chemical analy-

TABLE 6.—*Protein and phosphorus content of composite forage samples.*

Plot No.	Treatment	Composition of samples			
		Aug. 4–5, 1939		July 8, 1940	
		Protein, %	Phosphorus, %	Protein, %	Phosphorus, %
1	Treated, severe grazing	11.00	0.273	12.27	0.291
3–4	Untreated, severe grazing	9.68	0.173	9.25	0.177
2	Treated, moderate grazing	15.81	0.331	13.87	0.294
5	Untreated, moderate grazing	8.88	0.169	10.80	0.221
6	Treated	17.44	0.280	15.31*	0.302
8	Untreated	14.81	0.242	—	—
7	Treated	20.94	0.383	13.19*	0.259
9	Untreated	7.13	0.134	10.56*	0.166

*Sampled April 26, 1940.

ses of vegetation are obvious, but not necessarily the most important. Analyses of composite samples do not indicate the amount of protein or phosphorus contributed by the particular species relative to the total. Legumes usually contain larger quantities of protein than grasses and composite samples of variable botanical makeup cause differences in composition.

Table 6 indicates that forage samples from treated plots Nos. 1, 2, 6 and 7 contained higher percentages of protein and phosphorus than those from untreated plots Nos. 3–4, 5, 8, and 9. This relationship existed on both severely and moderately grazed plots. Soil treatment was the most important in influencing the protein and phosphorus content of these forage samples. There is some indication that good grazing management, particularly on treated land, has increased protein and phosphorus content although the data are insufficient to be conclusive.

Table 7 presents chemical analyses of forage species that were separated from hay samples during 1940 and 1941. These samples included Korean lespedeza, *Lespedeza stipulacea;* Orchard grass, *Dactylis glomerata;* and redtop, *Agrostis alba*. Insufficient material for complete analysis precluded the analysis of other species.

Korean lespedeza.—Percentages of protein and phosphorus were higher in samples obtained from plots Nos. 1, 2, 6 and 7, all of which received limestone and phosphate, than from plots Nos. 3–4, 5, 8 and 9 which received no treatment. A phosphorus content of 0.133, 0.138 and 0.130, as found in samples obtained in September, 1940, from plots 1, 3–4, and 5, respectively, falls below a minimum nutritional requirement considered adequate for livestock (4). In 1941 the percentages of protein content on treated and untreated plots were similar to those of 1940, but the phosphorus content was higher on treated plots.

TABLE 7.—*Protein and phosphorus content of Lespedeza stipulacea, Dactylis glomerata, and Agrostis alba in forage samples, 1940–41.*

Plot No.	Treatment	1940				1941			
		June 18		Sept. 16		June 21, 25		Sept. 17, 18	
		Protein, %	Phosphorus, %	Protein, %	Phosphorus, %	Protein, %	Phosphorus, %	Protein, %	Phosphorus, %
				Lespedeza					
1	Treated, severe grazing	—	—	13.88	0.133	16.94	0.197	18.19	0.255
3–4	Untreated, severe grazing	—	—	13.13	0.138	13.75	0.153	—	—
2	Treated, moderate grazing	—	—	15.75	0.187	16.69	0.206	18.38	0.243
5	Untreated, moderate grazing	—	—	12.88	0.130	13.44	0.160	17.66	0.225
6	Treated	—	—	16.56	0.210	—	—	19.19	0.261
8	Untreated	—	—	14.38	0.196	—	—	—	—
7	Treated	—	—	17.94	0.256	—	—	16.06	0.276
9	Untreated	—	—	15.69	0.206	—	—	19.31	0.230

	Orchard Grass								
1	Treated, severe grazing	——	0.344	——	——	6.94	0.201	17.44	0.454
3–4	Untreated, severe grazing	——	——	——	——	6.00	0.264	——	——
2	Treated, moderate grazing	11.63	0.342	10.25	0.349	——	——	——	——
5	Untreated, moderate grazing	——	——	——	——	6.50	0.283	——	——
6	Treated	8.06	0.212	11.38	0.257	5.88	0.267	11.81	0.476
8	Untreated	6.31	0.134	10.75	0.185	6.06	0.151	12.19	0.310
7	Treated	6.13	0.135	11.94	0.274	6.81	0.263	12.75	0.475
9	Untreated	8.50	0.168	11.19	0.192	6.25	0.145	12.69	0.300
	Redtop								
1	Treated, severe grazing	10.00	0.297	9.44	0.231	7.63	0.208	15.94	0.318
3–4	Untreated, severe grazing	8.38	0.184	9.81	0.191	9.44	0.163	——	——
2	Treated, moderate grazing	8.00	0.266	9.25	0.219	5.38	0.141	14.19	0.247
5	Untreated, moderate grazing	8.44	0.188	8.75	0.172	6.81	0.149	12.44	0.176
6	Treated	8.38	0.209	10.38	0.212	6.25	0.236	12.13	0.302
8	Untreated	6.81	0.147	9.88	0.209	5.88	0.160	11.13	0.227
7	Treated	6.25	0.194	11.38	0.241	6.69	0.215	13.94	0.314
9	Untreated	6.13	0.147	10.31	0.206	5.06	0.142	12.69	0.195

*Blank spaces indicate that insufficient material was available for chemical analysis.

Orchard grass.—Applications of limestone and phosphate made little difference in the protein content of this species. With one exception, soil treatment increased the percentages of phosphorus. In all cases samples cut in September contained larger percentages of phosphorus than samples obtained in June.

Redtop.—This grass is an important basic species in pastures and meadows of southern Illinois. This is due to its edaphic and ecologic adaptation to the area. No consistent differences in protein content were found between treated and untreated plots. As in the case of orchard grass, applications of limestone and phosphate increased the percentages of phosphorus in forage samples. Samples from plots Nos. 8 and 9 cut in June, 1940, and of plots Nos. 2, 5, and 9 cut in June, 1941, fell below the minimum phosphorus content that is necessary for livestock requirements.

Although little information is available on the influence of associated legumes on the composition of grasses, samples of both orchard grass and redtop cut in September, particularly in 1941, contained relatively high percentages of protein.

SUMMARY

Results for a 4-year period are presented on an experiment conducted at the Dixon Springs Experiment Station by the Soil Conservation Service, Research Division, U. S. Dept. of Agriculture, and the Illinois Agricultural Experiment Station. The purpose of the experiment is to determine the effect of intense and moderate grazing and of soil treatment on soil and water losses and forage values of permanent pasture land.

Plots 1/3 acre in size on which severe and moderate grazing was practiced were established on both treated and untreated land. Runoff plots 70×14 feet in size were located within each grazing area.

Application of limestone and phosphate and the use of regulated grazing reduced runoff during the 4-year period, July, 1938, through June, 1942. The lowest runoff was obtained from the treated and moderately grazed plot, which lost only 3.4% of the total precipitation of 140.10 inches.

Soil losses in runoff were low from all plots. The value of permanent pasture cover in controlling erosion is emphasized by the low quantities of soil lost from the plots.

The amounts of various plant species in samples of hay taken from protected areas within each grazing unit are reported in pounds per acre. During the period under investigation, the amount of Kentucky bluegrass in hay samples from the treated, moderately grazed area increased from 250 pounds per acre in 1940 to 850 pounds from the first cutting in 1942. Only small amounts of bluegrass were present on the untreated plots.

The number of days grazing with sheep and the gains or losses in weight from the various plots are presented. During the first season of severe grazing, two to three times as many days pasturage were obtained from the severely grazed plots as from the moderately grazed plots. During the following years, on treated land, approxi-

mately the same number of days of pasturage were obtained from both severely and moderately grazed plots. Gains expressed in pounds of live weight per acre showed an increase of 132 pounds on treated land in favor of the pasture that was moderately grazed. On the untreated plots, the gains in weight of sheep were 79 pounds per acre in favor of the plot with regulated grazing. On the basis of the returns from these plots, soil treatment should pay for itself within a 2-year period.

Botanical composition of forage was obtained by the vertical point quadrat method. The results indicated that Kentucky bluegrass increased on treated land at the same time that orchard grass and timothy were being eliminated from the stand. On untreated land, the percentage of redtop was higher than the percentage of any other grass, and it persisted longer in the stand. The results show that Kentucky bluegrass is the most desirable permanent pasture grass for a continuous cover on treated land in the area, and that redtop is the best grass available for pasturage on untreated soils. The frequency of occurrence of lespedeza on the various plots varied with soil treatment and grazing management. Close grazing reduced the cover provided by lespedeza. Satisfactory stands of lespedeza were maintained only by moderate grazing and by treating the soil. Weeds were much more prevalent on severely grazed than on moderately grazed plots and on untreated than on treated plots.

Composite forage samples were analyzed for crude protein and phosphorus content. Forage samples from treated plots contained higher percentages of protein and phosphorus than samples from untreated plots. In some cases, the amounts of phosphorus in individual species were lower than the minimum percentage which is considered adequate for the nutritional requirements of livestock.

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NOTES

EFFECT OF NITROGEN ON ANTHER COLOR IN KENTUCKY BLUEGRASS[1]

IN certain seasons, fields of Kentucky bluegrass, *Poa pratensis* L., have a bluish cast at the time of anthesis. This fact is believed to be the basis for the common name given to this grass. The presence of the bluish cast seems to be associated with a purple color in the inflorescence.

While making notes on inflorescences of Kentucky bluegrass in 1940, it was observed that 48 out of 49 clones had yellow or greenish-yellow anthers. One clone had purple anthers and it was thought at the time that the color of the anthers might be used in inheritance studies. In 1941, however, most of these same clones had purple anthers. Weather conditions in the two years were widely different; 1940 was wet and cloudy and 1941 was dry and sunny throughout the period of seed production. It seemed probable, therefore, that environmental rather than hereditary factors had the greatest effect on anther color.

In 1941, an experiment in progress at the time of anthesis clearly indicated that the anther color was influenced by nitrate fertilization. In this experiment 3×3 foot plots were staked off in increase blocks of Kentucky bluegrass clones, Ky. 35, 50, and 52. $NaNO_3$ was applied at the rate of 300 and 600 pounds per acre with four replications of each treatment in each strain block. The weather was very dry and it was necessary to wash the $NaNO_3$ into the soil. Check plots received the same amount of water. At the time of application head emergence from the boot was taking place in the plants of strains 35 and 52. A similar stage of maturity was reached by the plants of strain 50 two weeks later. The effect of nitrogen was noticeable in a few days by the leaves of plants receiving nitrogen becoming much greener.

During anthesis marked differences were noted in the anther color. On nitrate plots there was distinctly less intensity of purple in the anthers that contained pigment and many anthers were yellow in contrast with anthers of plants in plots receiving no nitrogen which had an intense purple color. The anthers were collected and stored in stoppered vials for analysis. The number of anthers on the plots of a single treatment was insufficient for analysis and it was necessary to combine the anthers from all nitrate treatments and all checks from each strain to obtain enough for quantitative determinations.

When extracted for 12 hours with a mixture composed of 1 ml of ether, 4 ml of N/10 HCl, and 15 ml of 95% ethyl alcohol, the purple pigment in the anthers was changed to a red pigment. An absorption curve of the red pigment gave a maximum at about 535 mμ and this wave length was used in all concentration determinations. A Cenco-Sheard "Spectrophotelometer" was used in this work. No absolute concentration values were obtained, but a comparative measure of

[1]The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station and is published by permission of the Director.

pigment concentration was possible when the results were expressed as the extinction coefficient of the pigment solution per 100 grams air-dry weight of sample. The extinction coefficient of a pigment solution obeying Beer's law is proportional to concentration and may be defined as:

$$\text{Extinction coefficient} = \frac{\log \frac{I_0}{I}}{l} = \text{concentration} \times \text{constant, where } I_0$$

= intensity of radiant energy transmitted by solvent-filled cell; I = intensity of radiant energy transmitted by solution-filled cell; and l = thickness of solution layer in cm. The results are given in Table 1.

It is clear from the results presented in Table 1 that the anthers from treated Kentucky bluegrass strains contained significantly less pigment than those from the same strains receiving no $NaNO_3$. The larger difference in pigment content of anthers from treated and untreated plots in strain 50 may have been caused by its comparative immaturity when $NaNO_3$ was applied, since a longer time was available for the nitrate to become effective.

TABLE 1.—*The effect of $NaNO_3$ fertilizer treatments on the pigment content of Kentucky bluegrass anthers.*

Kentucky bluegrass strain No.	Treatment	Extinction coefficient per 100 grams	% less pigment in anthers from nitrated plots
35	None	98	—
	$NaNO_3$	31	68
52	None	100	—
	$NaNO_3$	39	61
50	None	96	—
	$NaNO_3$	12	88

The rate of nitrate application had an observable effect on anther color in the field, the heavier application producing a greater difference in pigment content, but sufficient material was not available for separate quantitative measurements in the laboratory. The effect of environmental conditions on its formation and its behavior in solution indicate that the purple pigment is an anthocyanin.—R. B. GRIFFITH, *Agronomy Department, Kentucky Agricultural Experiment Station, Lexington, Ky.*

AN IMPROVED HEAD THRESHER

THE difficulty of obtaining help during the present emergency to perform the tasks necessary for the effective prosecution of the plant breeding program in progress supplied the incentive for building a small head thresher that incorporates improvements which eliminate certain undesirable features found in some of the small threshers developed in the past and thus reduces the operational

labor requirements. The thresher described here and illustrated in Fig. 1 has been designed primarily for threshing single heads of wheat, but has also been satisfactorily used to thresh oats, barley, and sorghum and possibly may be found useful for threshing other crops.

With the exception of the drawer, cylinder, and concave, the lumber used was ¾ inch thick redwood. The parts of the thresher were assembled almost entirely with screws and bolts to permit of easy disassembly for repairs. The outside dimensions of the thresher excluding the motor are 5¾ inches wide, 8 inches long, and 9⅞ inches high. The front facing the operator has a narrow opening $\frac{13}{16}$ inch wide located 2⅛ inches below the top through which the heads of wheat are inserted in the threshing process. Directly in front of this opening is a movable hinged sheet metal baffle 1 inch wide which, when immediately closed following the insertion of the head, prevents the loss of seed that may occasionally be kicked out by the teeth of the cylinder when threshing. Below the feed opening is a right-angled, hinged shelf which extends downward 4 inches and outward 3¾ inches from the front of the thresher and serves as the feed table. The movability of this table permits raising it to inspect the interior. Below the feed table is an opening of $3\frac{1}{16}$ inches for the seed drawer which is $4\frac{15}{16}$ inches wide, $2\frac{15}{16}$ inches deep, and 8½ inches long. The sides, back, and bottom of the drawer are made of white pine wood ¼ inch thick. The front consists of a piece of redwood 5¾ inches long, 3 inches wide, and ¾ inch thick on the outside of which is screwed a metal drawer pull. To facilitate the removal of the chaff when cleaning the seed by means of blowing, an extra curved sheet-tin floor is placed in the drawer. The back of the thresher is enclosed to a point 2⅝ inches from the bottom.

The sides are constructed of two pieces, the lower $3\frac{1}{16}$ inches of each being reduced to half the thickness to prevent chaff and seeds from lodging on the narrow upper sides of the drawer, between the drawer and sides of the box, or on the metal overhang that has been used in some threshers to prevent this undesirable condition. On the top at the back of the thresher is a hinged door 4⅝ inches long and 5¾ inches wide which opens backward and permits the convenient removal of chaff or culms that may accidentally become lodged inside. The remaining front part of the top is permanently enclosed.

The cylinder, 4⅛ inches long and 2½ inches in diameter, is turned from a block of well-dried maple and in a ½-inch hole drilled through its center is inserted a steel shaft to fit. The shaft extends 3 inches beyond each end of the cylinder to allow for the passage through the sides of the box, the bearings, and the pulley. Four rows of teeth are equi-spaced diagonally across the cylinder, the teeth being screwed into undersized holes drilled ⅞ inch apart in the row to within $\frac{3}{16}$ inch of the ends of the cylinder. The square teeth are made by grinding down the heads and shanks of 1½-inch No. 14 screws and extend ⅞ inch from the perifery of the cylinder.

At a point on each of the two sides 3¼ inches from the top and 2¼ inches from the end a ½-inch hole is bored through which the shaft passes to the bearings. Three and seven-eighth inches from the top of

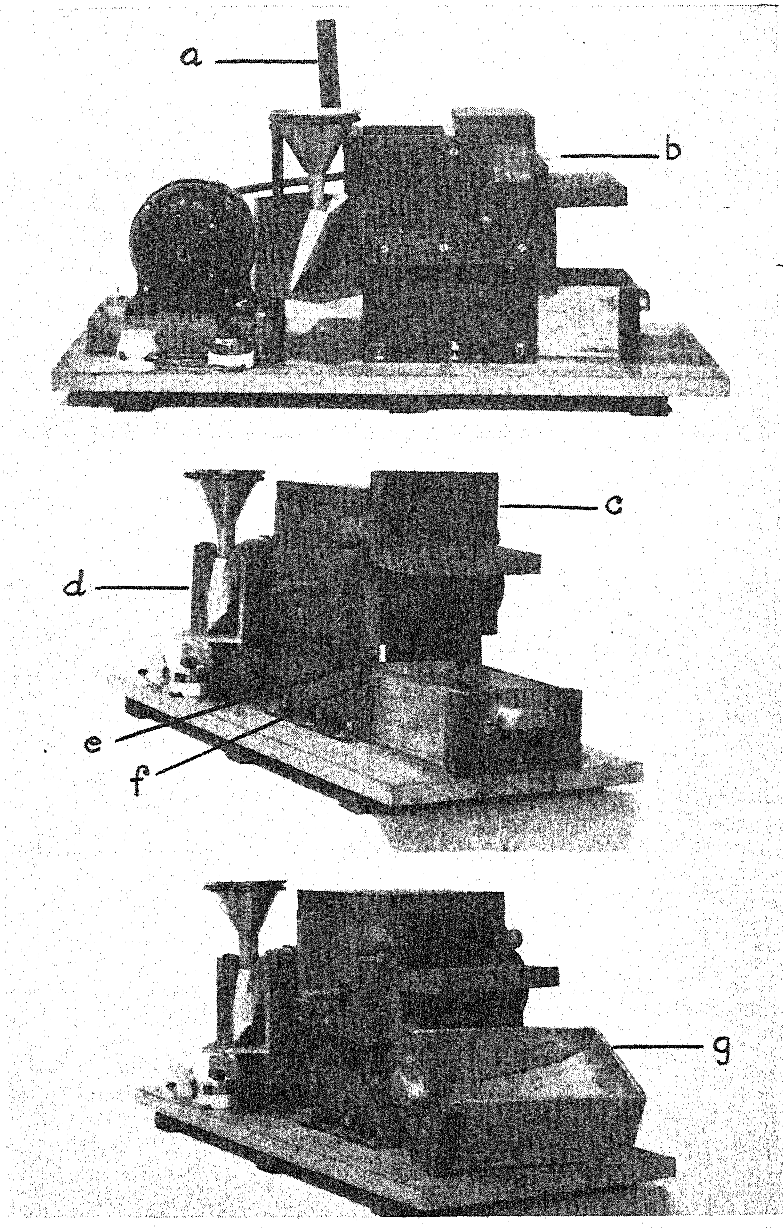

FIG. 1.—Three views of improved head thresher showing (a) door open for inspection of interior; (b) open baffle which is closed immediately after inserting head into feed opening to prevent seed loss; (c) feed table elevated for inspection of interior below cylinder; (d) seed envelope and holder with receiving funnel; (e) opening in back of thresher for rapid cleaning of thresher bottom; (f) inset for sides of drawer to eliminate lodging and mixing of seed; (g) curved tin bottom in drawer for facilitating the removal of chaff when cleaning grain by blowing.

the two sides are placed battens 1¼ inches wide and 7¼ inches long which serve as mounts for the bearings. The bearings consist of two pieces of bronze 3 inches long and ¾ inch wide bored to take the ½-inch steel shaft of the cylinder. A hole ¼ inch in diameter is bored into the top of each of the bronze bearings for lubricating. The concave, which is shaped to the cylinder from a block of maple wood by routing, rasping, and sanding, is secured above the cylinder by two screws inserted through each of the two sides of the thresher. Twelve teeth arranged in three straight rows ¾ inch apart are screwed into the concavity so that the teeth of the cylinder will clear them by about $\frac{3}{16}$ inch when threshing.

The thresher completely assembled is attached to a baseboard 27½ inches long and 11½ inches wide by bolting to two 7-inch lengths of ¾-inch angle iron. To permit the free movement of the drawer, the thresher is attached to the baseboard so that its front is 7½ inches from one end. A 1/20 H.P. motor placed on the baseboard in back of the thresher and operating at a speed of 1,425 revolutions per minute supplies the power for threshing. With a 2½-inch pulley on the motor shaft and a 3-inch pulley on the cylinder shaft, a speed of about 1,187 revolutions per minute is obtained by the latter. This speed has been found satisfactory for threshing wheat heads in this machine. A ½-inch belt 34 inches long connects the two pulleys. A base plug and snap switch are also conveniently located on the baseboard.

Two additional inovations that have contributed to the efficiency of the threshing operations are a seed-envelope filler and a notebook or pad holder (not shown) which have been attached to the thresher. The seed-envelope filler consists of a rectangular box 3×3×3½ inches devoid of two sides and the upper end. This box is constructed of ¼-inch plywood and is attached about midway to a piece of strap iron ⅛×⅝×10 inches that is bolted to the baseboard behind the thresher. At the apex of this piece of strap iron is bolted a ring 3½ inches in diameter of heavy wire which supports a small funnel. After threshing and cleaning, the seed is transferred to and readily passes through the funnel, the lower end of which is inserted into a seed-envelope 2½ inches wide and 4¼ inches long that rests on the envelope holder. Although this holder is extremely convenient, after becoming sufficiently familiar with the operation of the thresher it may be found preferable to transfer the seed from the drawer directly to the seed-envelope.

Frequently, while threshing, reference to notes or the recording of observations is required. The most convenient location for a notebook holder is in front of the operator on the thresher. A small notebook holder or writing-pad support has been designed that consists of a piece of plywood 8½ inches wide, 11½ inches long, and ¼ inch thick at the bottom of which is attached a piece of $\frac{5}{16}$ inch quarter-round that prevents the pad or notebook from sliding off the board. Two pieces of strap iron 9 inches long, ½ inch wide, and ⅛ inch thick are attached to the two sides of the thresher 4 inches below the top so that the apexes of the pieces of strap iron extend 1¼ inches beyond the back. Attached to the bottom of the plywood board 1¼ inches

from the back are two small sheet-metal angles that are bolted to the two pieces of strap iron at their upper ends, forming hinges that permit the board to be swung back when the door on the top of the thresher is opened for interior inspection. The bottom of the plywood board rests on a piece of strap iron ½ inch wide, 11¾ inches long, and ⅛ inch thick that is bent downward 3 inches from each end and screwed to the two sides of the thresher 1 inch below the top with a slight forward incline so that the board rests flat on the broad side of the strap iron.

The principal advantages of the threshing machine described are as follows:

1. *The saving of labor.*—The placing of the drawer at the front of the thresher and a notebook or writing-pad holder above the thresher permits inspection of the material to be threshed, recording of data, threshing, cleaning, and packaging by one man with a minimum of positional change. From three to five heads of wheat may be threshed and cleaned by an average operator in 1 minute.

2. *A reduction in the contamination and loss of seed while threshing.*—Insetting the drawer into the sides of the thresher box and locating the concave above the cylinder eliminates sources of lodging for seeds and the flexible baffle in front of the feed opening reduces seed loss.

3. *The facility in cleaning.*—The hinged door at the top and front of the thresher and the lower opening at the back permits the detection and expeditious removal of chaff and straws that may become accidentally lodged inside.

4. *Its portability and small space requirements.*—The small dimension of the threshing outfit permits its operation and storage in a very small area and its weight of 30 pounds is not burdensome when its transportation from one place to another is necessary.—W. J. SANDO, *Bureau of Plant Industry Station, Beltsville, Md.*

BOOK REVIEWS

RANGE MANAGEMENT

By Lawrence A. Stoddart and Arthur D. Smith. New York and London: McGraw-Hill Book Company, Inc. XII+547 pages, illus. 1943. $5.00.

THIS volume is by far the most complete work on the western range. The authors, who are professor and assistant professor, respectively, of range management at the Utah State Agricultural College, have covered apparently every phase of a subject vital not only to western agriculture but to the conservation of a great national resource. The scope of the book is suggested in the authors' definition of range management as "the science and art of planning and directing range use so as to obtain the maximum livestock production consistent with conservation of the range resources".

The importance of the subject is evident when we realize that the 17 states west of the 100th meridian known as the "western range" produce over 72% of the sheep, 71% of the beef cattle, and 41% of all cattle in the United States. More specifically, the book deals with

such subjects as the range and national economy, development of the range livestock industry, land policies, range physiography, range ecology, nutrition of range animals, range conservation, kinds of livestock for range grazing and their management, range development as regards water, roads, trails, fences, artificial seeding and burning, soil and water conservation, poisonous range plants, faunal relationships, and administration and economics of range lands. Excellent lists of references are given at the close of the chapters and a good index is included.

The book should be invaluable to anyone dealing with either the science or the art of range management and even the eastern and southeastern livestock farmer will find a wealth of material relevant to his grazing problems. (R. C. C.)

LIFE AND WORK OF C. F. MARBUT

A Memorial Volume, Assembled and Prepared for Publication by H. H. Krusekopf, University of Missouri. Published by the Soil Science Society of America, G. G. Pohlman, Secretary, Morgantown, West Virginia. 271 pages, illus. 1942. $2.00 postpaid.

FRIENDS and admirers of Doctor Marbut have been looking forward for several years to the appearance of this Memorial Volume. As Chief of the Soil Survey Division of the U. S. Bureau of Chemistry and Soils, Doctor Marbut was always an outstanding figure at all of the meetings of the American Soil Survey Association. When this organization joined with the Soils Section of the American Society of Agronomy to form the present Soil Science Society of America, it voted to use the funds remaining in its treasury to finance the publication of a Memorial Volume of Doctor Marbut's works. A special committee, consisting of M. F. Miller, chairman, of the University of Missouri, W. E. Ekblaw of Clarke University, A. R. Whitson of the University of Wisconsin, and Mark Baldwin of the U. S. Dept. of Agriculture, was appointed to plan the volume. The material was assembled and prepared for publication by Professor H. H. Krusekopf of the University of Missouri.

The book was planned to give as appropriate a picture as possible of the life and work of Doctor Marbut. A brief foreword by Professor M. F. Miller is followed by a short but very interesting and intimate biography of Doctor Marbut's daughter, Louise Marbut Moomaw. Under the heading, "A Measure of the Man," is republished the series of short sketches of Doctor Marbut which originally appeared in the Russian journal, PEDOLOGY. These were written by various colleagues from all over the world.

A series of four articles which give a critical appraisal of various phases of his work was prepared especially for this volume by four of his American colleagues, *viz.*, R. S. Smith, A. G. McCall, C. B. Manifold, and H. H. Krusekopf. This section is followed by a complete bibliography of Doctor Marbut's published papers. Eleven of the more representative papers are then presented in full. Abstracts and reviews of his other important papers and books were prepared by E. B. Branson, H. L. Shantz, C. E. Kellogg, and James Thorp.

The book contains many interesting and characteristic photographs which will give those who never had the privilege of knowing Doctor Marbut personally a clearer picture of him as a man. To those of us who knew him well, they will serve to recall many treasured memories. This book is worthy of a place in every soil science library in the world, whether private or public. (R.B.)

AGRONOMIC AFFAIRS

THE NATIONAL SEED CAMPAIGN TO REPLENISH THE SCORCHED EARTH

THE seed campaign which has been conducted for the past year and particularly since last July in the United States and Canada for Russia, has assumed quite unexpected proportions. About a million pounds of vegetable seeds have already been shipped to Russia, half of which were contributed and the other half were purchased with the funds contributed for that purpose. In addition to these vegetable seeds of all kinds, large quantities of cereal, forage, legumes, and other farm crop seeds have been contributed by farmers either through the statewide campaigns in various states or, as in North Dakota, Nebraska, Minnesota, South Dakota, Iowa, Arizona, California, and several provinces in Canada, the extension department of the agricultural college, particularly the extension agronomist, representatives of the state Farm Bureau Federation, representatives of the seed trade and grain elevators designated a committee, composed of three to five persons, in every county to solicit cash. With the cash thus obtained, seed grown in the particular states was purchased and sent on to the Pacific ports and from there they were sent directly to Russia.

North Dakota has sent over 11 carloads weighing over 1 million pounds; Minnesota sent 5 carloads weighing over 400,000 pounds; Nebraska sent 2 carloads of oats weighing 130,000 pounds; etc.

In states where no statewide committees were organized, contributions were made largely through the State Crop Improvement Association of which the extension agronomist is usually the secretary. Certified seeds of all cereals and hybrid seeds of corn were contributed in this way from Iowa, Wisconsin, Illinois, Indiana, Ohio, Texas, Oklahoma, Arizona, California, etc.

In addition to these commercial seeds, a special shipment of experimental seeds was sent at the request of the Russian Governmental Commission for Testing Crops. Twenty-five state agricultural experiment stations in the United States were approached and requested to send from 4 to 112 pounds of the different new varieties of wheat, barley, oats, as well as corn and corn hybrids, alfalfa, clover, flax, beans, and soybeans. In Canada, through the cooperation of Dr. L. H. Newman, Dominion Cerealist of the Experimental Farms of Canada, 24 bags of the most valuable planting material were obtained.

Many of the experiment stations also sent small quantities of their latest developments in various farm and vegetable crops. Through Dr. W. G. Morse a collection of 36 varieties of soybeans were sent;

Professor A. C. Dillman supplied 12 varieties of flax; the late Dr. Westover enabled us to obtain a dozen different varieties of alfalfa. Other specialists in the U. S. Dept. of Agriculture and in the experiment stations sent in specimens of grasses, clover, tobacco, beans, tomatoes, collards, and many other of their novelties.

The plant breeders have not only supplied their planting material freely, but they have also supplied the latest printed or mimeographed matter giving full description of their latest planting material. These printed descriptions will be particularly valuable to the hundreds of Russian agronomists and plant breeders who are anxious to keep up their plant breeding work during the Nazi invasion. A great deal of this material has already arrived at its destination, and as soon as reports on the plants are available, they will be communicated through the pages of your esteemed publication. May I take this opportunity, on behalf of the American National Seed Committee and the Russian agronomists, to extend most sincere thanks to the splendid response received from the members of the American Society of Agronomy and all other agronomists and plant scientists who have shown in many ways their interest in helping the brave Russians to keep up their agricultural science.—J. W. PINCUS, *Seed Consultant, Russian War Relief, Inc., 11 East 35th Street, New York.*

NEWS ITEMS

DOCTOR E. R. PURVIS, Soil Technologist, Virginia Truck Experiment Station, has been granted a leave of absence for the duration of the war and has been serving as Major in the Army since April, 1941.

—A—

J. M. BLUME, Assistant Soil Technologist, has been granted a leave of absence for the duration of the war and has been serving as Pharmacist in the U. S. Naval Reserve since December, 1940.

—A—

ACCORDING TO SCIENCE, Professor D. C. Tingey of the Department of Agronomy, Utah State College, has been given leave of absence to become Senior Agronomist of the Bureau of Plant Industry, U. S. Dept. of Agriculture, in the guayule production project in California and the southwestern states.

—A—

PROFESSOR JOHN HALL BARRON, Extension Professor of Field Crops at Cornell University since 1914, has retired from active service. Prof. Barron holds the distinction of being the manager of the first county Farm Bureau in the United States, in Broome County, N. Y.

—A—

JOHN H. LONNQUIST has joined the Department of Agronomy, University of Nebraska, as corn breeder. Mr. Lonnquist spent two years at Kansas State College and one year at Ohio State University in graduate work.

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ASSOCIATIONS BETWEEN SPECIES OF GRASSES AND LEGUMES[1]

EWERT ÅBERG, I. J. JOHNSON, AND C. P. WILSIE[2]

IN A preliminary report in 1939, Ahlgren and Aamodt (1)[3] explained differences in field performance of certain species of grasses and legumes, when grown alone and in mixture, on the basis of harmful root interactions. Data from a greenhouse study showed that the individual plant forage yields of Kentucky bluegrass, Canada bluegrass, redtop, and timothy were generally lowered when grown in some combinations with these grasses, although the differences were not statistically significant. The weight of roots per plant was found to be significantly less for timothy grown in association with redtop and for Canada bluegrass grown with Kentucky bluegrass. In other combinations the root yields were lowered, but the differences did not exceed the 5% level of significance.

Benedict (2) found that bromegrass produced a substance, or several substances, in the substratum inhibitory to its own growth. It was suggested that the inhibiting substance or substances were derived from dead roots. In a study in which bromegrass plants were grown in quartz sand, mixed with 7 and 25 grams, respectively, of oven-dried bromegrass roots, the results showed a highly significant reduction in the dry weights of the plants grown in pots to which the roots were added.

The possible production of inhibitory substances from dead roots has a direct bearing on studies in root growth reported by Stuckey (4). From these investigations Stuckey divided the grasses into two groups, one having "annual" and the other having "perennial" roots. For grasses with annual roots, all roots were regenerated each year and the old ones disintegrated shortly after the new ones became established. In grasses with a perennial root system maximum production of roots occurred during the first year and these roots, for the most part, remained functional for more than one year. Some

[1]Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa. Journal paper J-1061. Project 171. Received for publication November 6, 1942.

[2]Research Associate in Farm Crops while on leave of absence from the Agricultural College, Uppsala, Sweden, and Research Professor, and Research Associate Professor of Farm Crops, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 369.

new growth was made during the second fall and spring and some disintegration of the first formed roots occurred on perennial roots, but the new growth as well as the decay was small when compared with the original root growth. Likewise it was small compared to the root growth and decay of plants with annual roots. Stuckey included timothy, redtop, meadow fescue, rough-stalked meadow grass, perennial ryegrass, and probably colonial bent in the annual group and Kentucky bluegrass, Canada bluegrass, orchard grass, and crested wheatgrass in the perennial group.

Wilson (5) concluded that when white clover was cut the nodules on its roots were destroyed by decomposition and the nitrogen liberated to the soil became available to the nonlegume grown in association. This nitrogen relationship may have a pronounced effect on grass yields when grown with legumes.

Roberts and Olson (3) recently published results of a greenhouse study on grass and legume associations very similar in design to the present investigation. Six legumes, including red, alsike, white, and sweet clover, alfalfa, and lespedeza, and two grasses, redtop and bluegrass, were grown alone and the grasses with each of the six legumes. Dry weight of tops were obtained for two cuttings and root yields at the final harvest. Analysis also was made for nitrogen in the roots and tops. From this study it was concluded that in no cases were both the grass and legume benefitted or injured when grown in association. In general, an increase in dry weight of one component of the mixture resulted in a decrease in dry weight of the other in comparison with their respective yields when grown alone. A similar conclusion was drawn in respect to nitrogen content of the crops. Gains in dry weight and total nitrogen were attributed to the wider spacing of the more vigorous component of the mixture resulting in more effective use of the plot area.

Unfortunately, the results obtained by Roberts and Olson (3) cannot be compared with those to be reported here because the same specific combinations of grasses and legumes were not used. The principles involved, however, are comparable. It should be emphasized, as will be shown later, that the results from a study of plant associations are probably dependent largely upon the particular environmental conditions under which the investigation was made and that definite conclusions cannot be drawn until the various factors of the growth have been analyzed separately.

MATERIAL AND METHODS

The investigations to be reported here were intiated with a field study in 1940. Four species, including two legumes, alfalfa and red clover, and two grasses, bromegrass and timothy, were established in a field nursery from seedlings transplanted from the greenhouse when 6 weeks old. Each of the four crops and the six possible combinations of two each were space-planted 6 inches apart, alternating the species in mixtures both within and between rows. The 10 treatments were arranged in a randomized block design with three replications. Seedlings that failed to survive after transplanting were replaced and the final stand was complete. Each plot consisted of 288 plants (12 rows of 24 plants each) from

which the two outside and end border rows were eliminated at harvest. Forage yields were taken in August of the first year of growth for each crop in the mixture and for the crops grown alone. Dry matter samples from each plot or component of a plot were saved for nitrogen analysis.

The field study was made only for a single season because of complete winter-killing of red clover resulting from the severe storm in November 1940.

The investigation was continued in the greenhouse during the winter of 1941–42 with three grasses, bromegrass (Heinese strain), timothy, and orchard grass (commercial strains), three legumes, alfalfa (Ladak), red clover (Midland), and sweet clover (Iowa Late). These six crops were planted in 4-gallon crocks 10 inches in diameter and 12 inches deep as pure stands and in the 15 combinations of two each to make a total of 21 treatments. The soil used consisted of two thirds Webster clay loam and one third fine sand. The soil and sand were thoroughly mixed after the soil had been screened by sifting over a ¼-inch mesh screen and the appropriate species of Rhizobium added to insure inoculation of the legumes.

In the pure stands and mixtures, two or three seeds were planted on September 23–25 2 inches apart with alternate spacing in the mixtures. The seedlings were thinned to a single plant basis and seedlings transplanted, when seed failed to germinate, to obtain a perfect stand of 24 plants in each pot. The experiment was arranged in a randomized complete block with five replications.

The greenhouse was maintained at a temperature of 65° to 70° F during the day and 60° to 65° F at night. The first harvest was made on January 27–28, when red clover was in bloom, the second crop was cut on March 23–24, and the final yield was taken on May 12–13. The top growth at each harvest date was cut about 1 to 1½ inches above the soil, separated into the two crops in the association, and the forage dried at 180° F for 1 week prior to making dry weights. After the final harvest was made, the roots were washed from the pots, separated in water, and dried as previously described to obtain dry weights.

EXPERIMENTAL RESULTS

FIELD STUDIES

The data on dry weights of forage per plant obtained in 1940 for the two grasses and two legumes grown alone and in all combinations are summarized in Tables 1 and 2. Although the yield per plant of bromegrass was higher in all combinations than when grown alone, in no cases were the differences significant. Timothy yields were somewhat higher in association with alfalfa but lower when grown with bromegrass and red clover. In contrast, the alfalfa yields when grown with bromegrass and red clover were significantly less than when grown alone but not different when grown with timothy and alfalfa. The error variance for all crops except alfalfa was comparatively high which emphasizes the need for a larger number of replications than used in this study to determine significant interactions from plant associations.

The gain or loss in yield of a crop in any combination should be evaluated in terms of the similar response of the associated crop to determine if the combination is antagonistic, compensating, or beneficial. The data in Table 2 show the deviation in grams per plant for each of the two crops in the association from their yields when

grown alone. For example, the yield of bromegrass with timothy was 2.83 grams per plant more than when grown alone, while the

TABLE 1.—*Yield of dry forage in grams per plant for each of four crops grown alone and in association.*

Crop	Associated crop, yield in grams			
	Bromegrass	Timothy	Alfalfa	Red clover
Bromegrass	9.78*	12.61	13.06	12.41
Timothy	3.54	5.64*	6.28	4.51
Alfalfa	4.91	8.44	7.97*	6.04
Red clover	5.14	8.87	9.24	7.97*

Analysis of Variance

Source of variation	D.F.	Mean squares			
		Bromegrass	Timothy	Alfalfa	Red clover
Total	11	—	—	—	—
Replications	2	2.67	0.28	0.77	4.64
Treatments	3	6.58	4.42	8.19**	10.36
Error	6	4.97	2.22	0.45	4.17

*Yields when grown alone.
**Exceeds the 1% point in level of significance.

TABLE 2.—*Average deviation in grams of forage per plant for each crop grown in combination from its yields when grown alone and of the associated crop in the same combination from its yields when grown alone.*

Crops grown in combination	Associated crop			
	Bromegrass	Timothy	Alfalfa	Red clover
Bromegrass	—	2.83	3.28	2.63
Associated crop	—	−2.10	−3.06**	−2.83
Net gain or loss	—	0.73	0.22	−0.20
Timothy	−2.10	—	0.64	−1.13
Associated crop	2.83	—	0.47	0.90
Net gain or loss	0.73	—	1.11	−0.23
Alfalfa	−3.06**	0.47	—	−1.93*
Associated crop	3.28	0.64	—	1.27
Net gain or loss	0.22	1.11	—	−0.66
Red clover	−2.83	0.90	1.27	—
Associated crop	2.63	−1.13	−1.93*	—
Net gain or loss	−0.20	−0.23	−0.66	—

*Exceeds the 5% point in level of significance.
**Exceeds the 1% point in level of significance.

yield of timothy was 2.10 grams less in association than when grown alone. Hence the gain in yield of bromegrass was nearly offset by the loss in yield of timothy. In nearly all cases in this study the plant associations were compensating except for slight nonsignificant gains for both timothy and alfalfa when grown in combination. In no cases was a lower yield obtained for both crops grown in combination, but a slight negative difference was found between the gains for one crop and losses for the other in three of the six combinations. The results from this study would therefore indicate that with these crops there was no evidence for either an antagonistic or beneficial effect from their association as measured in yield per plant.

The nitrogen percentages given in Table 3 for each crop grown alone and in combination were not greatly modified by the plant associations. Bromegrass grown with red clover had a somewhat higher nitrogen percentage than when grown alone, but when grown with alfalfa the nitrogen percentage was slightly lower. The nitrogen content of timothy grown alone was slightly higher than when grown either with legumes or with bromegrass. None of the differences due to plant association were statistically significant. These results might be expected because this test was grown on highly productive Webster soil. Advantages to the grasses from nodule decomposition therefore might be very slight during the first year of growth.

TABLE 3.—*Nitrogen percentage for each of four crops grown alone and in association.*

Crop	Associated crop, percentage N			
	Bromegrass	Timothy	Alfalfa	Red clover
Bromegrass	2.60*	2.85	2.54	2.88
Timothy	1.51	1.61*	1.51	1.51
Alfalfa	2.66	2.71	2.51*	2.76
Red clover	2.37	2.51	2.35	2.39*

Analysis of Variance

Source of variation	D.F.	Mean squares			
		Bromegrass	Timothy	Alfalfa	Red clover
Total	11	——	——	——	——
Replications	2	0.0070	0.0110	0.0039	0.0074
Treatments	3	0.0910	0.0067	0.0337	0.0150
Error	6	0.0311	0.0206	0.0111	0.0036

*Grown alone.

GREENHOUSE STUDIES

The data from the study under greenhouse conditions are summarized in Tables 4 to 9, inclusive. The growth of each of the crops grown alone during the period from September 23 to May 12 as shown by their yields of dry matter for the three harvest dates

indicates their relative performance under the conditions of this study. The data given in Table 4 clearly show that the grasses yielded less for the second and third harvest while the legumes made their greatest growth between the second and third harvest period. From

TABLE 4.—*Yield of dry forage in grams per plant for each of the crops grown alone at three dates of harvest.*

Date harvested	Grams per plant					
	Bromegrass	Orchard grass	Timothy	Alfalfa	Sweet clover	Red clover
Jan. 27–28	3.58	4.26	5.76	4.60	6.52	7.20
Mar. 23–24	2.00	2.20	1.90	6.44	5.78	9.60
May 12–13	1.76	3.56	2.00	9.38	15.02	15.48

TABLE 5.—*Average yield of dry forage in grams per plant from three cuttings of three grasses and three legumes grown alone and in association.*

Crop	Associated crop					
	Bromegrass	Orchard grass	Timothy	Alfalfa	Sweet clover	Red clover
Bromegrass	2.45†	1.17	1.41	2.79	2.65	1.63
Orchard grass	4.01	3.34†	3.44	4.37	4.24	2.92
Timothy	4.42	2.20	3.22†	4.67	4.76	2.80
Alfalfa	9.37	4.80	5.91	6.81†	7.34	2.52
Sweet clover	12.30	7.60	8.38	7.43	9.11†	2.73
Red clover	16.16	13.48	13.71	19.07	16.49	10.76†

Analysis of Variance

Source of variation	D.F.	Mean squares					
		Bromegrass	Orchard grass	Timothy	Alfalfa	Sweet clover	Red clover
Total	89	—	—	—	—	—	—
Replications	4	1.63	6.78	4.79	4.17	6.64	6.76
Dates	2	37.51**	77.32**	162.92**	333.05**	721.64**	2102.76**
Treatments	5	7.27**	4.93**	17.59**	81.88**	144.16**	126.33**
Dates × treatments	10	0.28 *	2.19**	2.15**	29.77**	49.94**	25.45**
Dates × replications	8	0.20	0.86	0.87	1.76	4.92	6.88
Treatments × replications	20	0.37	0.76	1.72	2.18	7.38	10.14
Dates × treatments × replications	40	0.12	0.25	0.55	0.73	4.20	5.94

*Exceeds the 5% level of significance.
**Exceeds the 1% level of significance.
†Grown alone.

the analysis of variance in Table 5 the mean squares for dates of harvest for each crop were highly significant when tested against dates × replications. The differential response of the grasses and legumes in successive harvest dates undoubtedly influenced their respective yields when grown in association.

The average yield of forage for the three harvests for each crop grown alone and in combination is summarized in Table 5. From the analysis of variance of these data, the mean squares for treatments were highly significant for all crops when tested against treatments × replications, indicating a marked response of each crop when grown in various combinations. For the grasses, the yield per plant of bromegrass was lower when grown in association with orchard grass, timothy, and red clover in comparison with its yield when grown alone. Orchard grass yielded more when grown with bromegrass, alfalfa, and sweet clover, and timothy yields were increased when grown in association with bromegrass, alfalfa, and sweet clover but decreased when grown with orchard grass. The above-noted differences either exceeded the 5% or 1% level of significance.

Among the legumes, the yield per plant of alfalfa was higher when grown with bromegrass and lower when grown with orchard grass and red clover when compared with its yield in pure stands. Sweet clover yields were increased in combination with bromegrass but decreased with red clover, and red clover yields were higher when grown with all of the grasses and legumes. These differences were all either significant or highly significant statistically. A study of the yields of the crops grown alone, indicates a fair relationship between their vigor and their ability to compete with the associated crop. The yield of bromegrass alone was lower than any of the grasses, and in three of the five combinations the yield of bromegrass was significantly depressed. In contrast, red clover growth was excellent, and in all five associations its yield was significantly increased. Orchard grass yields were higher than either timothy or bromegrass, and in three of the five associations its yields were significantly increased. Timothy, alfalfa, and sweet clover gave both significantly higher and lower yields in specific associations. These results, in general, agree with the conclusions reached by Roberts and Olson (3) that the yields of the most vigorous member of an association is likely to be increased because of its advantage in competition for space.

As previously stated, root yields of each crop grown alone and in association were obtained after the final harvest. These data are given in Table 6, together with the mean squares for the analysis of variance. The treatment mean squares were significant for all crops, indicating differences in root yields for the crops grown alone or in combination. The weight of roots per plant of all grasses was significantly higher when grown with the distinctly tap-rooted legumes alfalfa and sweet clover in comparison with their root yields when grown alone. The root yields of orchard grass and timothy, the most aggressive grasses under greenhouse conditions, also were significantly higher when grown with bromegrass. The root yields of red clover

were significantly higher in all combinations than when grown alone. Sweet clover yields were significantly lower in association with orchard grass. In general, the agreement between significant gains or losses in yield of forage and weight of roots was reasonably good, except for bromegrass. For this crop, however, the trend was similar to that of the others.

TABLE 6.—*Yield of dry roots in grams per plant from three grasses and three legumes grown alone and in association.*

Crop	Associated crop					
	Brome-grass	Orchard grass	Timothy	Alfalfa	Sweet clover	Red clover
Bromegrass ...	4.82†	3.96	3.30	9.54	11.12	3.20
Orchard grass..	11.48	7.48†	8.98	15.34	19.00	7.22
Timothy......	5.92	3.26	4.46†	6.74	7.04	3.86
Alfalfa........	12.50	7.10	9.46	10.20†	12.76	3.86
Sweet clover...	9.08	4.26	6.92	5.32	7.50†	1.50
Red clover.....	12.94	14.66	12.72	14.72	14.46	8.80†

Analysis of Variance

Source of variation	D.F.	Mean squares					
		Brome-grass	Orchard grass	Timo-thy	Alfalfa	Sweet clover	Red clover
Total........	29	—	—	—	—	—	—
Replications ..	4	19.15	52.46	6.99	0.87	13.80	4.79
Treatments...	5	59.43**	111.78**	12.38**	57.48**	33.74**	25.53*
Error........	20	4.80	7.69	0.87	6.18	5.47	6.91

*Exceeds the 5% level of significance.
**Exceeds the 1% level of significance.
†Grown alone.

The summaries in Tables 7 and 8 were prepared from Tables 5 and 6, respectively, to show gains or losses for each crop grown in association from its yield when grown alone and also for the associated crop in the mixture from its yield when grown alone. For example, the yield of bromegrass in orchard grass was 1.28 grams per plant less than when grown alone, but the yield of orchard grass in this combination was 0.67 gram more than when grown alone, or a net loss of 0.61 gram per plant for the association. Although the reduction in the yield of bromegrass was significant and the gain for orchard grass was significant, the net loss was not statistically significant. This association may then be considered as compensating. In four cases among the 15 combinations the net gains were significant. Three of the significant increases were combinations of bromegrass, the least vigorous crop under greenhouse conditions, with each of the legumes. As shown in Table 4, the legumes were more productive than the grasses, particularly in the third harvest, and the increased yield of these combinations was probably due to this factor. The

significant increase for the alfalfa-red clover combination was due to the extremely large increase (77%) for red clover which more than compensated for the highly significant decrease for alfalfa. In no case was there a significant increase or a significant decrease for both crops in an association. Evidence is therefore lacking for either mutually beneficial or antagonistic associations among these crops under the conditions of this study during the first year of development. If substances inhibiting growth are produced from dead roots as suggested by Benedict (2), the occurrence of antagonistic associations would not be expected until later in stages of growth and particularly for those crops classified by Stuckey (4) as having annual roots.

From a comparison of field and greenhouse results (Tables 2 and 7), it is evident that the crop responses in similar associations were very different. In the field, the yield per plant of bromegrass was higher

TABLE 7.—*Average deviation in grams of forage per plant for each crop grown in combination from its yields when grown alone and of the associated crop in the same combination from its yield when grown alone.*

Crops grown in combination	Associated crops					
	Brome-grass	Orchard grass	Timo-thy	Alfalfa	Sweet clover	Red clover
Bromegrass	—	−1.28**	−1.04**	0.34	0.20	−0.82**
Associated crops	—	0.67*	1.20*	2.56**	3.10**	5.40**
Net gain or loss	—	−0.61	0.16	2.90**	3.39**	4.58**
Orchard grass	0.67*	—	0.10	1.03**	0.90*	−0.42
Associated crops	−1.28**	—	−1.02*	−2.01**	−1.51	2.72*
Net gain or loss	−0.61	—	−0.92	−0.98	−0.61	2.30
Timothy	1.20*	−1.02*	—	1.45**	1.54**	−0.42
Associated crops	−1.04**	0.10	—	−0.90	−0.73	2.95
Net gain or loss	0.16	−0.92	—	0.55	0.81	2.53
Alfalfa	2.56**	−2.01**	−0.90	—	0.53	−4.29**
Associated crops	0.34	1.03**	1.45**	—	−1.68	8.31**
Net gain or loss	2.90**	−0.98	0.55	—	−1.15	4.02**
Sweet clover	3.19**	−1.51	−0.73	−1.68	—	−6.38**
Associated crops	0.20	0.90*	1.54**	0.53	—	5.73**
Net gain or loss	3.39**	−0.61	0.81	−1.15	—	−0.65
Red clover	5.40**	2.72*	2.95*	8.31**	5.73**	—
Associated crops	−0.82**	−0.42	−0.42	−4.29**	−6.38**	—
Net gain or loss	4.58**	2.30	2.53	4.02**	−0.65	—

*Exceeds the 5% level of significance.
**Exceeds the 1% level of significance.

TABLE 8.—*Average deviation in grams of roots per plant for each crop grown in combination from its yields when grown alone and of the associated crop in the same combination from its yields when grown alone.*

Crops grown in combination	Associated crops					
	Brome-grass	Orchard grass	Timo-thy	Alfalfa	Sweet clover	Red clover
Bromegrass	——	-0.86	-1.52	4.72*	6.30**	-1.62
Associated crops	——	4.00*	1.46*	2.30	1.58	4.14*
Net gain or loss	——	3.14	-0.06	7.02**	7.88**	2.52
Orchard grass	4.00*	——	1.50	7.86**	11.52**	-0.26
Associated crops	-0.86	——	-1.20	-3.10	-3.24*	5.86**
Net gain or loss	3.14	——	0.30	4.76*	8.28**	5.60*
Timothy	1.46*	-1.20	——	2.28**	2.58**	-0.60
Associated crops	-1.52	1.50	——	-0.74	-0.58	3.92*
Net gain or loss	-0.06	0.30	——	1.54	2.00	3.32*
Alfalfa	2.30	-3.10	-0.74	——	2.56	-6.34**
Associated crops	4.72*	7.86**	2.28**	——	-2.18	5.92**
Net gain or loss	7.02**	4.76*	1.54	——	0.38	-0.42
Sweet clover	1.58	-3.24*	-0.58	-2.18	——	-6.00**
Associated crops	6.30**	11.52**	2.58**	2.56	——	5.86**
Net gain or loss	7.88**	8.28**	2.00	0.38	——	-0.14
Red clover	4.14*	5.86**	3.92*	5.92**	5.86**	——
Associated crops	-1.62	-0.26	-0.60	-6.34**	-6.00**	——
Net gain or loss	2.52	5.60*	3.32*	-0.42	-0.14	——

*Exceeds the 5% level of significance.
**Exceeds the 1% level of significance.

in association with timothy, alfalfa, and red clover than when grown alone. Although the differences were not significant the trend was consistent in all combinations. In contrast, under greenhouse conditions, the yield of bromegrass was significantly lower in association with timothy and red clover and not significantly different when grown with alfalfa. The performance of bromegrass in the field and greenhouse was thus almost entirely reversed. On the basis that the highest yielding crop gains when grown in association, the field results obtained from bromegrass would have been expected. In the field study, alfalfa yielded significantly lower in association with bromegrass and red clover, but in the greenhouse study its yields were significantly higher with bromegrass and also lower with red clover. Timothy and red clover also yielded less when grown with bromegrass in the field, but significantly higher when grown in the greenhouse. This lack of agreement emphasizes the importance of environmental conditions as a factor in studies of crop associations.

From a study of deviations in root yields of each crop in the association (Table 8), in 6 of the 15 combinations the net gains were significant. In four of these cases one of the crops yielded less, but not sufficiently lower to compensate for the gains made by the other crop in the association. In two combinations, bromegrass-alfalfa and bromegrass-sweet clover, the root yields for both members were higher than for either crop grown alone, but only one crop in each association was significantly higher. In nine comparisons the gains made by one crop were compensated by losses in the other crop of the association. Therefore, as was found from similar comparisons for forage yields, there was no evidence for either mutually beneficial or antagonistic associations among the crops grown in this study.

The comparative advantage of combinations of grasses with grasses, grasses with legumes, legumes with grasses, and legumes with legumes is summarized in Table 9. To obtain the deviations given in this table, the yield per plant, for example, of bromegrass alone was subtracted from the average yield of bromegrass in combination with orchard grass and timothy. In the above comparison the yield of bromegrass was reduced by 1.16 grams per plant when grown in association with the two grasses, but not significantly reduced when grown with legumes. The data for all of the grasses indicate a slight but nonsignificant advantage in yield of forage when grown with the legumes. The results, however, are not conclusive. The yield of grass roots in association with legumes was in all cases significantly higher than when grown alone, while the grasses grown with grasses were in all cases not significantly different from their yields when grown alone. These results may be attributed to less competition for root development for a fibrous-rooted crop when grown in association

TABLE 9.—*Average deviations in grams of forage and of roots per plant for the grasses grown in combination with grasses and legumes and for legumes grown in combination with legumes and grasses in comparison with each crop where grown alone.*

Combinations	Crops					
	Brome-grass	Orchard grass	Timothy	Alfalfa	Sweet clover	Red clover
			Yield of Forage			
Grasses with grasses..	−1.16*	0.38	0.09	——	——	——
Grasses with legumes	−0.09	0.52	0.86	——	——	——
Legumes with legumes	——	——	——	−1.88	−4.03*	7.02**
Legumes with grasses	——	——	——	−0.12	0.32	3.69
			Yield of Roots			
Grasses with grasses..	−1.19	1.75	0.13	——	——	——
Grasses with legumes	3.13*	6.37**	1.42*	——	——	——
Legumes with legumes	——	——	——	−1.89	−2.73	5.89**
Legumes with grasses	——	——	——	−0.02	−0.75	4.64*

*Exceeds the 5% level of significance.
**Exceeds the 1% level of significance.

with a tap-rooted legume, particularly in this experiment where large pots were used. The data on legume-legume and legume-grass associations would indicate that sweet clover was better able to compete with grasses than with the legumes. Alfalfa and sweet clover each yielded lower when grown with legumes. Although the yield of these two legumes also was lowered when grown with grasses, the reduction in yield was not as great. These differences, however, were not statistically significant.

SUMMARY

1. Two grasses and two legumes were grown alone and in all combinations of two each in space-planted field plots, and three grasses and three legumes were studied in a similar manner under greenhouse conditions.

2. The results from the field plot study indicated that bromegrass was better able to compete with other crops in mixture than either timothy, alfalfa, or red clover. Alfalfa yielded significantly lower in association with bromegrass and with red clover than when grown in pure stands.

3. The nitrogen percentages were not significantly different for grasses grown in association with legumes and grown alone.

4. In the greenhouse study the forage yields of bromegrass were significantly lower when grown in association with orchard grass, timothy, and red clover than in pure stands. Orchard grass and timothy each yielded significantly higher in association with bromegrass, alfalfa, and sweet clover, and timothy yields were significantly reduced when grown with orchard grass. Alfalfa and sweet clover yields were significantly higher with bromegrass and significantly lower with red clover. Alfalfa yields also were reduced in competition with orchard grass. Red clover yielded significantly higher in association with all five of the crops than in pure stands.

5. The yield of roots in the greenhouse study was in agreement with gains or losses in forage yields of the crops grown in association. All of the grasses had a significantly higher yield of roots when grown in association with alfalfa and sweet clover, indicating that the fibrous-rooted grasses utilized the soil area not occupied by these tap-rooted legumes.

6. In no case in either the field or greenhouse study was there a significant gain or loss in forage or root yields for both members of an association. Significant gains or losses in yield for one crop usually resulted in significant losses or gains respectively for the other crop in association. The significant gains in a crop combination usually were made by the most vigorous crop and the losses by the least vigorous crop, under the conditions of these experiments. Response of crops in mixtures was of the compensating type rather than mutually beneficial or antagonistic.

7. The results obtained from the same crops grown in the greenhouse and field were in many cases reversed. This lack of agreement emphasizes the importance of environmental conditions in studies of crop association.

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SEEDLING EMERGENCE OF SMALL-SEEDED LEGUMES AND GRASSES[1]

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THE poor stands of seedlings frequently associated with the culture of the small-seeded legumes and grasses have often hindered the use of many of these valuable crops. It appears evident from the high cost of seeds, the frequency of undesirable stands, and the value of these crops to a permanent agriculture that a need exists for critical investigation of the factors that influence seedling emergence.

The results of a study of certain of these factors are presented in this paper. Major consideration is given to the effect on seedling emergence of depth of planting, mulching, kinds of crop seed, size of seed, and soil differences.

REVIEW OF LITERATURE

In reporting the cause of poor stands of seedlings, Thatcher, Willard, and Lewis (5)[3] state that critical experiments on depth of planting are lacking, but that they observed thin stands following deep seeding with a seed drill. They are of the opinion that a relationship exists between date of seeding and depth of coverage upon seedling emergence; and that in the spring, after the soil becomes dry enough to work, coverage is increasingly important. Kinney, Kenny, and Fergus (2); Ahlgren (1); and Murphy and Arny (3) found that grass and legume seeds, unless planted very shallow, did not produce a high percentage of emerged seedlings. Williams (6) observed that poor stands of red clover resulted from plantings made while the surface soil was wet, because of the number of seeds that would cling to the upper surface of the wet clods. Furthermore, he believes that lack of food reserve in the seedling accounts for poor seedling emergence when plantings are made at a depth of 2 or 3 inches.

Thatcher, Willard, and Lewis (5) found that organic mulches were extremely valuable in preventing the formation of hard crusts and in maintaining over a long period of time sufficient soil moisture for the establishment of seedlings. The extent to which the mulch aids seedling emergence, however, was not determined.

No data have been obtained relative to the interactions on seedling emergence of such factors as depth of plantings, mulching, kind of crop seed, seed size, and soil.

MATERIALS AND METHODS

Some of the studies here reported were carried out at Columbus, Ohio, and some at Knoxville, Tenn. At Columbus, plantings were made in the greenhouse on Miami silt loam and Brookston silty clay loam, and in the field on Miami silt

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[3]Figures in parenthesis refer to "Literature Cited", p. 381.

loam and on the 11 other soil types listed in Table 8. The Knoxville studies were made on Cumberland silt loam in both the field and the greenhouse. A firm and well-pulverized seedbed was prepared on all experimental plots so that accurate depths of planting could be obtained. The seeds were planted in rows 4 inches apart and 5 feet long. The plantings consisted of four replications. Rapid planting at accurate depths was obtained with the type of "depth digger" represented in Fig. 1. The soil was moistened slightly before the furrows were dug, in order to prevent it from caving into the small furrows made with the diggers. In making the furrows the diggers were moved along the galvanized iron tracks, the soil being scooped out of the trench. Seedbeds in the greenhouse were watered often

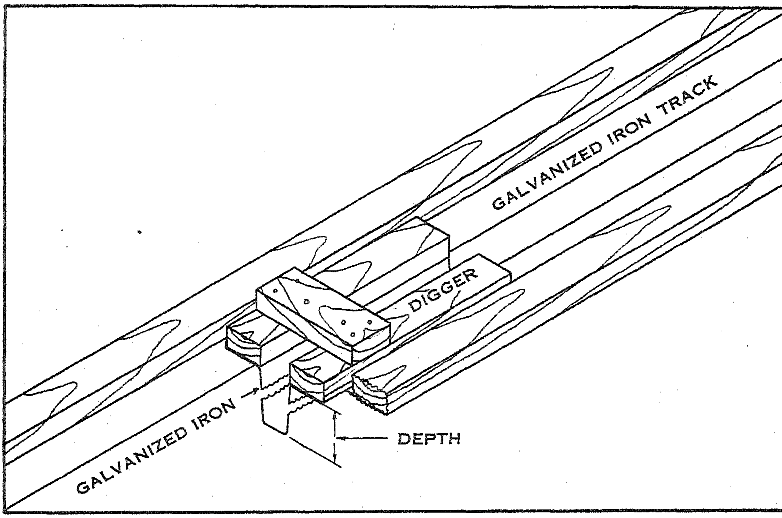

FIG. 1.—Apparatus used to obtain accurate depths of planting.

enough to prevent the formation of a dry crust on the surface of the soil. Experiments in the field were not artificially watered. The soil used in the greenhouse was sterilized with steam; soil in the field was not sterilized.

High-quality seeds of the following crops were used: Red Clover, *Trifolium pratense;* alfalfa, *Medicago sativa;* white sweetclover, *Melilotus alba;* yellow sweetclover, *Melilotus officinalis;* alsike clover, *Trifolium hybridum;* Korean lespedeza, *Lespedeza stipulaceae;* Kobe lespedeza, *Lespedeza striata;* Tennessee No. 76 lespedeza, *Lespedeza striata;* sericea lespedeza, *Lespedeza sericea;* crimson clover, *Trifolium incarnatum;* orchard grass, *Dactylis glomerata;* timothy, *Phleum pratense;* and Sudan grass, *Sorghum vulgare.*

Data from the emergence test were analyzed by the analysis of variance method. Minimum significant and highly significant differences were determined at the 5% and 1% levels, respectively, as listed by Snedecor (4). Appropriate round-hole screens were used to separate a commercial sample of crimson clover seed into the different sizes used in determining the influence of seed size on seedling emergence. The sizes of screens used are listed in Table 4, according to the diameters of the holes.

Mulching effects were secured on the mulched plots by application of wheat

straw to the surface of the plots at the rate of 1 ton per acre. The straw was placed on the plots immediately after the plantings were completed and remained there throughout the tests.

Temperature readings were taken with a laboratory thermometer, the bulb being placed within the upper inch of soil. Representative soil samples were collected at the same time for moisture determinations. In all tests the seedling emergence counts represent the percentage of viable seeds that produced emerged seedlings. Emergence counts were taken daily. Each seedling counted was marked with a speck of red paint to prevent recounting on subsequent days.

TABLE 1.—*Emergence of seedlings of different crops planted on two soils under greenhouse conditions at Columbus, Ohio, 1939.*

Crop	Depth of planting, in.	Percentage of viable seeds that produced emerged seedlings by the 25th day after planting*		
		Miami silt loam	Brookston silty clay loam	Difference in emergence on Brookston and Miami soils
Red clover	0	56	62	6
	1/4	96	100	4
	1/2	90	100	10
	1	84	94	10
Alsike clover	0	54	66	12
	1/4	86	100	14
	1/2	70	100	30
	1	52	92	40
Alfalfa	0	42	68	26
	1/4	100	100	0
	1/2	100	100	0
	1	96	88	-8
White sweet clover	0	56	48	-8
	1/4	70	72	2
	1/2	64	90	26
	1	54	64	10
Yellow sweet clover	0	54	50	-4
	1/4	80	76	-4
	1/2	78	86	8
	1	64	94	30
Orchard grass	0	76	84	8
	1/4	98	100	2
	1/2	100	100	0
	1	78	100	22
Timothy	0	64	73	9
	1/4	88	94	6
	1/2	80	72	-8
	1	38	44	6

*Minimum significant and highly significant difference in percentage emergence between depths within soil types, or within depths between soil types, are 16 and 20, respectively.

RESULTS

Results for the depth-of-planting studies are reported separately for greenhouse trials and field trials.

GREENHOUSE TRIALS

Table 1 shows the results of a depth-of-planting study conducted at Columbus, Ohio. The percentage of viable seeds of red clover, alsike clover, alfalfa, white sweet clover, yellow sweet clover, orchard grass, and timothy producing emerged seedlings was generally greater in the Brookston soil than in the Miami. The ¼- and ½-inch depths of planting were found to give better emergence of seedlings than either the surface or 1-inch depth. The smallest seeded crops—alsike clover and timothy—emerged better from the ¼-inch than from the ½-inch depth of planting. The reduction in emergence of these two crops caused by the 1-inch depth of planting was also much greater than that for the larger seeded crops.

Results from a comparative study of four kinds of lespedeza planted at 5 depths on sterilized Cumberland silt loam soil at Knoxville, Tenn., are presented in Table 2. It may be observed from these data that, except from Korean, fewer seedlings emerged from 1-, 1½-,

TABLE 2.—*Emergence of seedlings of lespedeza planted in Cumberland silt loam at Knoxville, Tenn., 1939.*

Kind of lespedeza	Depth of planting, in.	Percentage of viable seeds that produced emerged seedlings within number of days after planting indicated								Living seedlings not emerged by 49th day, %
		6	9	12	15	19	24	36	49*	
Kobe	¼	11	25	40	50	74	84	93	94	0
	½	5	13	40	55	79	88	96	97	0
	1	0	2	14	28	45	60	77	80	4
	1½	0	0	4	10	16	22	40	43	35
	2	0	0	0	0	0	1	2	2	60
Korean	¼	45	65	80	86	88	90	91	91	1
	½	49	70	84	90	91	92	92	92	0
	1	0	25	70	85	90	92	95	95	0
	1½	0	1	30	52	65	71	79	79	1
	2	0	0	0	1	4	8	9	9	10
Tenn. No. 76	¼	0	4	34	51	66	84	93	94	0
	½	0	0	16	49	67	82	88	89	0
	1	0	0	3	10	24	36	55	58	22
	1½	0	0	0	0	0	0	1	2	77
	2	0	0	0	0	0	0	0	0	74
Sericea	¼	0	0	9	25	54	71	82	83	0
	½	0	0	2	10	44	60	76	77	2
	1	0	0	0	2	10	19	33	35	8
	1½	0	0	0	0	0	2	6	6	13
	2	0	0	0	0	0	0	0	0	17

*Minimum significant and highly significant differences in final emergence (49th day) are 13 and 17, respectively.

and 2-inch depths than from the ¼- and ½-inch depths. The seedlings also emerged earlier from the more shallow depths of planting. Good early emergence was associated closely with seedling vigor and total emergence.

Many of the seedlings that did not emerge from the 1½- to 2-inch depths of planting were still alive on the 49th day of the test. These weakened seedlings had all elongated to approximately the same extent. The longevity of the seedling of Korean and sericea lespedeza that did not emerge was not as great as that of similar seedlings of Kobe and Tennessee No. 76.

Table 3 is a summary of the study of influence of depth of planting upon the emergence of Sudan grass seedlings. In this trial a high percentage of early emergence with the associated high percentage of total emergence was obtained from 1- and 2-inch depths of planting.

TABLE 3.—*Emeregnce of seedlings of Sudan grass planted in Cumberland silt loam at Knoxville, Tenn., 1939.*

Depth of planting, in.	Percentage of viable seeds that produced emerged seedlings within number of days after planting indicated							
	3	4	5	6	8	10	12	14*
1	20	72	80	80	82	84	88	90
2	0	64	74	80	82	84	40	92
3	0	24	44	58	62	68	70	74
4	0	2	24	36	44	44	52	56
5	0	0	14	30	42	46	52	56

*Minimum significant and highly significant mean differences in total emergence (14th day) are 16 and 24, respectively.

Table 4 contains the results of seedling emergence from crimson clover seed of various sizes planted at different depths. The smallest number of seedlings emerged from the extra large seeds of crimson clover. The deeper plantings reduced the number of emerged seedlings from the extra large and extremely small seeds more than from the medium-sized seed. Total emergence for each seed size appears to be reduced by the 1- and 1½-inch depths of planting.

FIELD RESULTS

The following quantities of rain fell on the Columbus test reported in Table 5:

Date	Rainfall, inches
May 20	0.15
May 26	1.05
May 27	0.38
June 1	0.32
June 2	0.34
June 3	0.17
June 7	0.19
June 9	1.65
June 10	0.64
June 11	0.25

June 12	0.15
June 13	0.94
Total	6.23

Table 5 contains the results of the total emergence of seedlings for 10 crops, from six depths of planting, and from mulched and bare seedbeds on Miami silt loam.

The ¼- and ½-inch depths of planting permitted a high percentage of seedling emergence. The difference in emergence between the ¼- and ½-inch depths was significant only for timothy on the bare plots. Except in the case of Sudan grass, very few seedlings emerged from the 2-inch depth of planting.

Mulching proved to be valuable in promoting seedling emergence for all crops studied, except Sudan grass, and at all depths of planting. It proved more beneficial to some crops than to others. The response was greater for aslike clover and timothy than for the other crops at the optimum depths of planting. Mulching resulted, however, in a greater percentage increase of seedling emergence from the 0-, 1-, 1½-, and 2-inch depths of planting than from the ¼- and ½-inch depths. The data presented in Table 6 show that a mulch is effective in con-

TABLE 4.—*Emergence of seedlings from different sizes of crimson clover seeds planted in Cumberland silt loam in greenhouse at Knoxville, Tenn., 1939.*

Size of seeds	Depth of planting, in.	Percentage of viable seeds that produced emerged seedlings within number of days after planting indicated						
		4	5	6	7	9	12	15*
Extra large; over 1/15 in. screen	¼	4	80	82	82	84	84	84
	½	0	70	76	78	78	78	78
	1	0	22	58	72	72	74	74
	1½	0	2	22	58	68	70	72
Large; through 1/15 in. screen, over 1/16 in. screen	¼	4	92	92	92	92	92	92
	½	0	86	94	98	98	98	98
	1	0	16	64	86	88	90	90
	1½	0	0	10	66	84	86	86
Medium; through 1/16 in. screen, over 1/18 in. screen	¼	4	90	96	96	98	98	98
	½	2	76	90	94	96	96	96
	1	0	20	58	84	88	88	88
	1½	0	0	10	58	76	80	82
Small; through 1/18 in. screen, over 1/19 in. screen	¼	8	92	98	100	100	100	100
	½	0	78	92	100	100	100	100
	1	0	12	50	86	98	100	100
	1½	0	0	6	38	58	76	80
Extremely small; through 1/19 in. screen, over 1/20 in screen	¼	6	82	92	96	96	96	96
	½	0	78	96	100	100	100	100
	1	0	6	38	78	86	90	90
	1½	0	0	0	26	50	72	74

*Minimum differences in total emergence (15th day) to be significant and highly significant are 8 and 12, respectively.

TABLE 5.—*Emergence of seedlings under field conditions on Miami silt loam soil at Columbus, Ohio, test planted on May 18, 19, and 20, 1939.*

Crops	Percentage of viable seeds that produced emerged seedlings by the 25th day after planting at depth of planting indicated											
	Seedbed bare						Seedbed mulched					
	0 in.	¼ in.	½ in.	1 in.	1½ in.	2 in.	0 in.	¼ in.	½ in.	1 in.	1½ in.	2 in.
Alfalfa	42*	75	63	48	7	1	76	85	82	73	45	16
Yellow sweet clover	35	44	43	30	6	2	53	78	78	73	36	12
White sweet clover	15	34	30	15	2	0	49	60	62	42	15	5
Red clover	40	45	39	25	1	1	74	85	86	70	26	3
Alsike clover	39	21	22	7	0	0	70	91	91	46	7	1
Crimson clover	57	83	78	50	9	0	78	95	93	75	45	5
Korean lespedeza	48	88	82	33	3	0	70	96	92	66	9	1
Orchard grass	37	58	59	41	9	3	44	95	86	69	36	10
Timothy	30	46	27	3	0	0	49	70	68	23	1	0
Sudan grass	32	65	78	75	73	72	37	80	74	84	75	67

*Minimum significant and highly significant differences are 14 and 18, respectively.

serving soil moisture and in maintaining moderate temperatures within the seedbed. The data of Table 6 were taken from the test reported in Table 5.

TABLE 6.—*Soil moisture and temperature conditions in mulched and bare seedbeds on Miami silt loam, Columbus, Ohio, 1939.*

Time of sampling	Depth of sampling, in.	Soil temperature, °F		Soil moisture, %	
		Mulched	Bare	Mulched	Bare
May 23, 2 p.m.	0–1	—	—	11.7	6.7
	1–3	—	—	15.4	13.8
May 25, 1 p.m.	0–1	—	—	7.9	3.8
	1–3	—	—	14.8	13.3
May 26, 1 p.m.	0–1	93°	99°	—	—
	—	—	—	—	—
June 5, 5 p.m.	0–1	80°	91°	17.5	10.2
	1–2	—	—	17.8	14.7
June 6, 5 p.m.	0–1	86°	100°	15.7	6.6
	1–2	—	—	17.4	14.7

The rainfall during the investigation reported in Table 7 was as follows:

Date	Rainfall, inches
April 18	0.14
April 19	1.40
April 20	0.12

April 22	0.04
April 23	0.82
April 30	0.63
May 1	0.10
May 9	0.25
May 15	0.94
Total	4.34

Table 7 contains a summary of the seedling emergence from the field test on the Cumberland silt loam. Even though frequent rains occurred during this investigation, mulching in general proved to be beneficial to seedling emergence, especially for the 0, 1-, and 1½-inch depths of planting. The mulch enabled the surface of the seedbed to remain moist for several days following a rain. Mulching also lessened the degree of seedbed compaction caused by rainfall.

TABLE 7.—*Emergence of seedlings from seedlings made under field conditions on Cumberland silt loam soil at Knoxville, Tenn., planted April 18, 1940.*

Crops	Percentage of viable seeds that produced emerged seedlings by the 30th day after planting at depth of planting indicated									
	Seedbed bare					Seedbed mulched				
	0	¼ in.	½ in.	1 in.	1½ in.	0	¼ in.	½ in.	1 in.	1½ in.
Alfalfa	30*	78	70	50	38	56	70	82	62	42
Red clover	22	64	64	36	12	48	60	56	54	34
Yellow sweet clover	18	64	54	50	20	48	58	60	52	48
Kobe lespedeza	26	82	52	18	4	78	92	82	66	42
Tenn. No. 76 lespedeza	14	60	24	4	0	54	90	74	34	8
Korean lespedeza	22	90	74	28	8	76	84	80	76	28
Sericea lespedeza	10	34	16	4	0	32	58	44	18	4

*Minimum significant and highly significant differences are 14 and 20, respectively.

Optimum depths of planting in this trial were ¼ and ½ inch. With few exceptions there were only small differences in emergence between these depths. The largest crop differences in seedling emergence from the various depths of planting occurred for Tennessee 76 and sericea lespedeza. Seedling emergence in general was low for these crops, with emergence from the ¼-inch depth significantly better than that from the ½-inch depth.

The data of Table 8 indicate that large differences in seedling emergence may be expected among different soils. The soils that were of rather loose tilth, such as Clyde silty clay loam, Crosby silt loam, Trumbull silt loam, and Bellefontaine silt loam, permitted good seedling emergence from the 1-inch depth. Soils such as the samples of Upshur clay loam used in this test, whose tilth permitted the seedlings to dry out, gave low emergence from the shallow plantings.

TABLE 8.—*The emergence of seedlings of alfalfa planted on different soils at Columbus, Ohio, April 25 and 26, 1939.*

Soil	Percentage of viable seeds that produced emerged seedlings by the 25th day after planting at depth of planting indicated			
	0	¼ in.	½ in.	1 in.
Clyde silty clay loam...	10*	80	85	82
Miami silty clay loam..	1	36	43	36
Crosby silt loam.......	5	76	79	72
Blanchester silt loam...	2	16	47	35
Clermont silt loam.....	3	70	79	60
Cincinnati silt loam....	4	68	84	65
Trumbull silt loam.....	1	41	82	77
Muskingum silt loam..	11	78	63	51
Wooster silt loam......	21	67	68	51
Tyler silt loam........	16	71	74	73
Bellefontaine silt loam	42	81	79	74
Upshur clay loam......	1	10	22	66

*Minimum significant and highly significant differences between types within depths or within types between depths, are 17 and 23, respectively.

DISCUSSION

It is thought that the significance of the data presented can be brought out more readily by treating each factor affecting seedling emergence separately.

DEPTH OF SEEDING

Although the differences in the number of seedlings that emerged from the various depths of planting are large, these differences do not evaluate the relative effect of depth of planting on the vigor of the stand. The seedlings that emerged from plantings made at the 1- and 1½-inch depths, for example, were slower in emerging than those from the shallow plantings. They were also weaker at the time of emergence. The seedlings thus weakened continued to grow more slowly than seedlings from the shallow depths of planting, and therefore would be less able to compete with weeds. Many seedlings from the deeper plantings emerged by way of soil cracks and were buried by soil filling in during rainfalls. The deeper planting, by retarding seedling emergence, subjected these seedlings for a long time to such hazards as "damping off" organisms, soil crusts, and depletion of food reserves of the seedling, and at the same time permitted weed seedlings to develop into aggressive plants.

MULCHING

A straw mulch proved favorable to seedling emergence. The beneficial effects may be attributed to three factors related to the seedbed, *viz.*, (a) higher and less variable moisture content, (b) lower maximum temperature, and (c) less soil compaction by rainstorms.

The influence of a straw mulch in promoting emergence through the maintenance of a higher and less variable moisture content within the seedbed is shown by data in Tables 5 and 7. A mulch is especially beneficial in conserving moisture if atmospheric conditions favor the drying out of the surface layer of the seedbed. The magnitude of moisture conservation attributable to mulching may be observed from the data in Table 6.

Mulches are desirable also as protection to the seedbed against excessively high temperature, which may prove unfavorable to the germination and to seedling growth of crops, such as sweet clover, red clover, and alsike clover. The temperature difference between the mulched and bare seedbeds, as listed in Table 6, may offer a possible explanation for the exceedingly wide difference in the percentage of emergence of sweet clover, red clover, and alsike clover, as reported in Table 5.

Likewise, mulching may be very important to seedling emergence, on soils that tend to compact readily through reducing the heavy impact of rain. Numerous field observations verify the importance of this factor.

The data support the conclusion that a mulch may be very beneficial to seedling emergence if applied at the rate of 1 ton per acre. Observations have shown, however, that heavy applications of a mulch will injure the seedling stand if not removed shortly after seedlings emerge.

KIND OF CROP

The several crops showed wide differences in the percentage of emergence when subjected to various depths of planting and mulching, or to an interaction of the two treatments. Sericea and Tennessee No. 76 lespedeza show relatively low percentage emergence from all depths of planting where no mulch was used (Table 7). In both cases emergence was greatly increased by the use of a mulch. The emergence of these two crops seemed to be lowered more by the 1- and 1½-inch depths of planting than was that of alfalfa, Korean lespedeza, Kobe lespedeza, red clover, and yellow sweet clover.

Variations in crop response in the Columbus field test (Table 5) were much greater than those in the Knoxville field test (Table 7). This wide difference may possibly be attributed to the more unfavorable moisture content and the higher soil temperature of the Columbus trials. Previous observations have indicated that late spring plantings of crops such as red clover, sweetclover, and alsike clover are commonly associated with poor stands. The Columbus test not only verifies these observations but is suggestive of the extent of the loss of seedlings. All of the crops were greatly benefited by the use of a mulch, but alsike clover was influenced most.

Sudan grass gave very good emergence from the 2-inch depth. Since the seeds of this grass are larger than those of the other crops, it seems reasonable to expect good emergence from relatively deep planting.

Yellow sweet clover tended to give better emergence than white sweet clover from the deeper plantings. Previous observations at Columbus had shown that good stands of yellow sweet clover were

easier to obtain than similar stands of the white. A possible cause is the very rapid elongation of the root system of the yellow sweet clover.

SEED SIZE

That the size of seed is important in depth-of-planting tests is indicated by a study of seed sizes of crimson clover (Table 4). This crop was chosen mainly because the oval-shaped seeds were readily separated into different sizes by the use of screens. The fact that extra large seeds produced fewer emerged seedlings than other seed sizes may possibly be attributed to their abnormally large cotyledons. The lack of adequate food reserve likely accounts for the low emergence from the very small seeds at the 1½-inch depth of planting.

SOILS

The soils that tended to be of open structure gave better emergence from the surface and 1-inch level of planting than did the other soils. Differences in emergence equally as great as those shown in Table 8 could be expected among samples of the same soil type which had been subjected to slight modifications in environment. Though the tests do show that large differences in seedling emergence occur on different soils, observations suggest that the physical condition of the surface of the seedbed is of more importance in promoting seedling emergence than is soil type.

SUMMARY

1. Studies are reported on the influence of depth of planting, mulching, kind of crop seeds, seed size, and soils upon the emergence of several small-seeded legumes and grasses. Certain of the studies were designed to permit an evaluation of the interaction on seedling emergence of depth × treatment, depth × crop, and treatment × crop. These interactions were found to be highly significant.

2. Optimum emergence was obtained from the ¼- and ½-inch depths of planting. Seedlings that emerged from the deeper plantings not only were slower in emerging but also were much weaker than those that emerged from the optimum depths.

3. Mulching proved to be very beneficial to seedling emergence from all depths of planting. It favored emergence more from those depths that ordinarily result in the lowest percentage of emergence than it did from the optimum depths. It was especially valuable for plantings made during a time of infrequent rainfalls and low relative humidity.

4. Crops were affected differently by treatments consisting of depth of planting, mulching, and soil types.

5. The emergence of seedlings from either the extra large or extremely small crimson clover seeds was reduced to a greater extent by the deeper planting depths than was that from the medium-sized seed.

6. Difference in soil type influenced the emergence of alfalfa seedlings from various depths of planting.

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INHERITANCE OF GREEN FUZZ, FIBER LENGTH, AND FIBER LENGTH UNIFORMITY IN UPLAND COTTON[1]

J. O. Ware, W. H. Jenkins, and D. C. Harrell[2]

FUZZ color, fiber length, and fiber length uniformity are each considered by all in the cotton industry as important characteristics of commercial cotton varieties. Fuzz color may either be a harmful or a useful attribute. With fuzzy seed varieties the gin usually removes from the seedcoat some tufts of fuzz along with the lint. The presence in the lint of these tufts when derived either from an intense green or a dark brown seed fuzz coat, lowers the grade of the commercial sample.

Tyler (13)[3] called attention to the undesirability of intense green fuzz in the Russell variety. In some unpublished current work with F_1 hybrids of sea island×upland, the intense green or dingy brown fuzz color inherited from the sea island parent, was found by the writers to lower the grade of the lint sample. On the other hand, the more moderate shades of fuzz color, such as white, whitish gray, gray, or even light brown, if genetically stabilized, provide helpful varietal markers or identification characters in seed standardization work.

Considerable genetic work has been carried on in separate studies of fuzz color and of fiber length. Kottur (9), however, reported a study of the association of brown lint color and length of lint. The brown lint stock presumably had brown fuzz. The brown color in the F_2 was associated with short lint. The color came into the cross, however, with the lint of the longer parent. No information has come to the attention of the writers on the study of the inheritance of fiber length uniformity.

Inheritance studies of fuzz color within species and between species have been reported intermittently by a number of workers for the past 35 or 40 years. Harland (4) reviewed this work rather completely in 1939. However, the mode of inheritance of fuzz color in upland cotton (*Gossypium hirsutum*), except when associated with colored lint, has not been worked out very satisfactorily. Ware, Jenkins, and Harrell (15) have shown that the color of Nankeen lint and the corresponding fuzz color are definitely associated. Fuzz color study as associated with white lint among the many upland varieties is complicated by many natural shades of color and by the process of fading of some of these colors on exposure to light and other weather effects.

Inheritance of fiber length has been studied for a number of years, but cotton breeders have not been provided as yet with adequate information as to the hereditary behavior of the characteristic.

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[3]Reference by number in parenthesis is to "Literature Cited", p. 392.

Several handicaps have obstructed the work. In crosses within species parental length differences employed in such studies usually have not been sufficient in contrast to provide much differentiation in segregates. Crosses between species, such as upland×sea island (*G. barbadense*) and upland×Egyptian (*G. barbadense*), have provided much more extreme parental length, but in turn interpretation of the data has been hindered somewhat because of sterility, shedding of fruit forms, and consequently lack of boll production on a large percentage of plants in the F_2 and later generations.

Kearney (8) and also other workers have reported this unproductive condition occurring in such interspecies crosses. In his cross which was an upland×Pima (Egyptian) hybrid, Kearney studied fiber length as well as a number of other characteristics. Ware (14) reported study of fiber length, both in upland×Pima and upland× sea island crosses. Both workers reviewed previous literature on the inheritance of fiber length and rather recently Harland (4) supplied an additional review. He also named several interspecies crosses that produced forms of sterility. No previous genetic work on fiber length has been reported wherein the fibrograph[4] developed by Hertel has been utilized as the measuring device, except in a brief summary of this work in a South Carolina Agricultural Experiment Station Annual Report by Jenkins and Harrell (7). This instrument also provides an estimate of length uniformity.

Breeders have given attention to uniformity of fiber since the beginning of cotton breeding but depended upon observation or some sort of improvised method for determining the characteristic. Recently, however, much attention has been given to devising and using accurate instruments for evaluating this and other fiber properties, but application of these measurements has been chiefly to commercial lots and varieties and strains by cotton breeders.

MATERIALS AND METHODS

The cross involved in the beginning of this study was made between a Florida Green Seed[5] plant and a Rowden plant, the latter being the staminate parent. The stocks from which the pistillate parent was selected had been self-pollinated 8 years and the stock from which the staminate parent was chosen had been self-pollinated 5 years. In 1935 these stocks were obtained from the Arkansas Agri-

[4]This fibrograph (5, 6) is an optical instrument utilizing photovoltaic cells to measure the optical density of a combed sample of ginned lint and to trace a special form of length-frequency curve or fibrogram of this lint. Two tangents drawn to this curve, each in a specified manner, provide two values, one the average length of the fiber population used and the other the average of the longer half of this population. The former is referred to as the "mean" and the latter as the "upper-half mean". The upper-half mean is about the same as the cotton classers' staple length, being usually on the conservative side. Uniformity of length or a length-uniformity index is derived from the expression $\frac{\text{mean} \times 100}{\text{upper-half mean}}$. Fibers shorter than ¼ inch in the sample are disregarded by this instrument.

[5]While on the staff of the Arkansas Agricultural Experiment Station, Fayetteville, Ark., O. A. Pope obtained the Florida Green Seed Stock from the Florida Agricultural Experiment Station, Gainesville, Fla. This stock is probably the same as that locally collected in Florida and studied there by Carver (2).

cultural Experiment Station, Fayetteville, Ark., and transferred to the Pee Dee Experiment Station, Florence, S. C., where this work was carried on.

The original cross was made in 1938 and the F_1, F_2, and progenies of parents grown the two subsequent years, 1939 and 1940. In 1939, plants of the two parental progeny lines were crossed and the F_1 backcrossed. In 1940, seed of two of the 1939 crosses, four of the backcrosses (two to Florida Green Seed and two to Rowden), four of the self-pollinated F_1 plants, one of the self-pollinated Florida Green Seed plants, and three of the self-pollinated Rowden plants were planted. The two crosses providing the 1940 F_1's were grown from two of these Rowden plants which had been pollinated by the Florida Green Seed plant. This plant had been used also to pollinate two of the F_1 plants to produce the backcross on Florida Green Seed. The third Rowden plant had been used to pollinate two other F_1 plants to provide the backcross on Rowden. The four F_1 plants here cited produced the F_2 generation. By growing a new F_1 generation in 1940 and continuing the parental lines that year, these groups of plants could be compared with the F_2 and backcrosses in the same season. The main portion of this study is concerned with the 1940 growth.

In order to classify the several groups of plants for fuzz color, suitable standards of color were set up. For grading seed having fuzz containing green color a series of eight grades, AH, BH, CH, DH, EH, FH, GH, and HH were established. These grades ranged in consecutive order from intense or bright pea green to grayish white fuzz, the latter having vestiges of green or a few green hairs present in the mat. For grading seed with white or grayish to gray fuzz and not having any greenish hairs, a series of seven grades, AR, BR, CR, DR, ER, FR, and GR, was provided. These grades ranged in consecutive order from very white to grayish white or gray color.[6]

After ginning each plant individually, the seed lots were graded for fuzz color by the established standards and the lint of each sent to the U. S. Cotton Field Station fiber laboratories[7] at Knoxville, Tenn., where fibrograph determinations were made.

RESULTS AND DISCUSSION

The Florida Green Seed stock, as the name implies, has green seed. The color of the seed fuzz of the original parents used in this study was intense green and classed as grade AH. The staple length of this plant was about 3/4 inch.[8] The Rowden stock used in this work

[6]Double alphabetical letter designations are used for the fuzz color grades since numerical digits have been adopted generally for fuzz pattern grades. In the white to gray or Rowden series, first letters "A" to "G" represent the color gradation or steps and the second letter, "R", appearing in each expression indicates the Rowden seed color type. In the series having gradations of green fuzz and representing hybrid material, the steps likewise, are indicated in the first letter of the expression by alphabetical order. The second letter, "H", of each expression is the initial for the word "Hybrid". The range of grades for the hybrid material, the F_1, F_2, and backcrosses is of sufficient width to include also the range of the Florida Green Seed parent. For this reason no separate series was needed for this parent. Fuzz color grades involving other colors and having this double letter plan of designation will be presented in a later paper.

[7]These determinations were carried out under the general direction of D. M. Simpson, who is in charge of the laboratory.

[8]The pulled staple length used here is the breeders' pull and not the commercial or Government classers' pull. It is not implied, however, that the pulled length here is different from the trade or official length.

had been selected for seed having white fuzz and the original parent used had fuzz graded as BR for color, which was about pure white. The staple length of this plant was about $1\frac{1}{32}$ inches or ¼ to 9/32 inch longer than that of the other parent. In 1939 the Florida Green Seed plant used in the crosses and backcrosses had a seed color grade of AH and a staple length of about 23/32 inch. The three Rowden plants used as parental material each had a seed color grade of BR and staple lengths, respectively, of about $1\frac{1}{16}$, $1\frac{1}{32}$, and 15/16 inch. The four F_1 plants used had a seed color grade of CH. One had a staple length of about $1\frac{1}{32}$ inch and the other three about 31/32 inch. Fibrograph tests were not made on the individual plants of 1939.

Eighteen plants had been grown in 1939 from the original 1938 Florida Green Seed parent plant. The seed of 10 of these was graded as AH, the grade of the parent, and 8 as BH, a slight fluctuation which may be attributed to change in color caused by exposure to light or to the personal equation in matching the seed with the standard. Among 17 of the 18 plants the staple length ranged from 11/16 to 13/16 inch, the other plant dropping to 19/32 inch. The average staple length of the 18 plants was 23.7/32 inch.

Fourteen plants had been grown in 1939 from the original 1938 Rowden parent plant. The seed of each was graded as BR, the same as the parent plant. Staple length of these plants ranged from 31/32 to $1\frac{1}{16}$ inches. The average staple length for the 14 plants was $1\frac{1}{32}$ inches.

Fourteen plants occurred in the 1939 F_1 group and the seed were all graded as CH, a shade somewhat less intense green than found in the green seed parent. This condition indicates that the green fuzz color is not completely or entirely dominant. Staple length of the 14 F_1 plants ranged from 15/16 to $1\frac{1}{32}$ inches and the average was 31.1/32 inch. Length of fiber is not completely dominant but ranges close to that of the Rowden or longer parental line.

In obtaining length measurements of the 1939 material by the fibrograph, six composited samples were taken from Florida Green Seed, 9 from Rowden, and 10 from the F_1. The average for *upper-half mean* length for the Florida Green Seed was 20.5/32 inch, for the Rowden 30.1/32 inch, and for the F_1 27.6/32 inch. The averages of the corresponding *means* for the three groups were 17.1/32, 26.2/32, and 23.8/32 inch, respectively. The average for the *length-uniformity index* was 83.6 for Florida Green Seed, 87.3 for Rowden, and 86.2 for the F_1. (See footnote 4 for method of computation.) The fibrograph length values confirm the data for length obtained by pulling, that is, that fiber length in the F_1 is much nearer that of the longer parent than that of the shorter parent.

The fiber within plants in the 1939 material appears to be most uniform in the Rowden, least uniform in the Florida Green Seed, and has an intermediate value in the F_1. This relationship was shown also among the parental lines and F_1 of 1940, but not to as marked a degree.

The individual plant values, expressed in *upper-half mean* length and in *length-uniformity index*, of the 1940 growth are stratified as frequencies according to the several groups of plants as well as in

accordance with the seed fuzz color grades within these groups. This arrangement for *upper-half mean*[9] length is shown in Table 1 and for *length-uniformity index* in Table 2.

In these tables the line progenies of the two Rowden plants which were used as pistillate parents for obtaining the 1940 F_1 are combined. Likewise, the corresponding F_1 plants are placed in one group. The line progeny of the Rowden plant which was used as the staminate parent of the backcross is in a separate group from that of the other Rowden material. The progenies from the four 1939 F_1 plants are combined as one F_2 group. The two backcross groups (one on Florida Green Seed and the other on Rowden) each is made up of plants from two pistillate parents.

SEED FUZZ COLOR

The 1940 Florida Green Seed line fluctuated or segregated into two fuzz colors grades, AH and BH, as did the 1939 line. The 1940 Rowden lines from the two parental plants of the 1940 F_1's produced seed graded as CR, while the line of the Rowden parent of the backcrosses broke or fluctuated into four grades, CR, DR, ER, and GR. This variation in grade was not expected since the three 1939 Rowden sibs that were used had the same grade, BR. Separate plants of the 1939 line happened to be used, two for production of the 1940 F_1 and the third as the recurrent parent of the backcross. Loss of brilliance in whiteness caused by weather exposure to some of the earlier opened bolls may have been responsible for the occurrence of the grayishness shown in some of the plants. The 1940 F_1 plants were classed in two grades, CH and DH; however, those of the 1939 F_1 had been placed in the former only. The F_2 plants ranged throughout the series of the eight green fuzz color grades. None of the white or Rowden-like grades reappeared. Over one-half of the F_2 population, however, reproduced the CH or the 1939 F_1 grade. The progeny of the backcross to the Florida Green Seed reproduced the two recurrent parental grades and the 1939 F_1 grade. The progeny of the backcross to the Rowden reproduced the 1939 F_1 grade, the DH grade which appeared in the 1940 F_1, and the three lightest grades of the F_2 range. From this backcross no grades for white or the Rowden fuzz color were recovered.

These results indicate that the inheritance of green fuzz color is much more complex than that shown by Carver (2) who, in 1929, reported a 3:1 ratio of green fuzz to nongreen or white fuzz for the F_2 generation. McLendon (10), in 1912, did not obtain information as definite as that of Carver. While the former showed dominance of green fuzz over white fuzz in the F_1, he did not find any clear-cut ratio in the F_2. In some of McLendon's crosses where both parents had white fuzz, the F_1 appeared as green, however. Also, in this connection, he stated that the green color had been observed by others in the same kind of cross, that no ratios at that time had been as-

[9]The *mean* length of the 1940 plants was likewise stratified, but it did not seem important to present an additional table showing this determination. This table is filed for any future reference that might be made to it.

certained in the F_2 for such crosses, and that it was very evident that a wide range of variation in fuzz color persisted in this generation.

FIBER LENGTH

The *upper-half mean* length value for each plant group and for the several individual seed fuzz color grades are arranged in frequencies, as previously stated, in Table 1. The 1940 parental lines and the F_1 check closely for this length value with the parental lines and the F_1 of 1939, except in the case of the progeny in 1940 of the Rowden plant used in pollinating the F_1 for producing the backcross. The *upper-half mean* in this Rowden line averaged about $\frac{1}{16}$ inch shorter than that of the lines from the Rowden plants used as pistillate parents of the 1940 F_1. The recurrent parent, as heretofore noted, had shorter lint than the other two Rowden sibs, but this, of course, could not be determined at the time the plant was chosen for providing the pollen.

The fiber length frequencies of the Florida Green Seed parental line and of the F_1, as shown in Table 1, approximate each other only while that of the latter overlaps the distribution of the Rowden parental line (related directly to the F_1) by one class interval. The modes of the three groups, however, indicate definitely separate populations. The F_2 distribution coincides closely with the F_1 distribution, except that the base of the former is somewhat wider. The averages of the *upper-half mean* length of the two groups are very nearly at the same level. The F_2 frequency is monomodal and falls far short of extending to the parental extremes, particularly on the lower side of the short parental distribution. In the progeny of the backcross to the Florida Green Seed, the fiber length of the plants ranged somewhat closer to those of the recurrent parent than to those of the F_1. Since a fairly high degree of dominance was shown in the F_1 itself, it would be expected, if simple character difference prevailed, that the length of this backcross would be nearer that of the F_1 than to that of the Florida Green Seed.

In the group of the backcross to the Rowden, the distribution and average of the *upper-half mean* length practically concided with those of the F_1. The recurrent Rowden parent did not exert any further pull on length. However, as previously noted, it was somewhat shorter than other Rowden plants used.

Not much inheritance study between long and short staple upland cottons that supplies consistent results has been carried out. Mell (11), in 1894, and before the discovery of Mendel's law, reported a number of crosses among leading upland varieties of that period. He tabulated and made comparisons of the fiber length of 25 of these crosses. Presumably the comparisons were those of the F_1 with respective parental varieties. Considerable variation as to degree of dominance of the longer length occurred which might be expected to some extent in open-pollinated commercial varieties. In eight crosses involving fiber length of 1 inch or less in both parents, the F_1 of six had length longer than either parent, one of the remaining of the eight F_1's had fiber length even with the longer parent, and the other

had fiber length nearer that of the shorter parent. In crosses of a variety having 1½-inch fiber on seven varieties each having fiber length 1 inch and less, the F_1 in none of these seven cases reached the length of the longer parent. In three of these cases the F_1 length was nearer the longer parent, in two cases half-way between, in one case

TABLE 1.—*Upper-half mean fiber length in thirty-seconds of an inch from a study of a Florida Green Seed × Rowden cross.*

Plant groups	Seed fuzz color grade*	Number of plants	Average of upper half mean	Length frequency by class intervals													
				19	20	21	22	23	24	25	26	27	28	29	30	31	32
Florida Green Seed, parental line	AH	18	20.7	1	3	11	3	—	—	—	—	—	—	—	—	—	—
	BH	5	21.4	—	1	2	1	—	1	—	—	—	—	—	—	—	—
	Total	23	20.9	1	4	13	4	—	1	—	—	—	—	—	—	—	—
Rowden, parental line of F_1	CR	19	31.3	—	—	—	—	—	—	—	—	—	—	1	1	7	10
F_1 generation	CH	19	27.7	—	—	—	—	—	—	1	2	1	11	4	—	—	—
	DH	3	27.7	—	—	—	—	—	—	—	—	1	1	1	—	—	—
	Total	22	27.7	—	—	—	—	—	—	1	2	2	12	5	—	—	—
F_2 generation	AH	1	24.1	—	—	—	—	—	1	—	—	—	—	—	—	—	—
	BH	8	26.3	—	—	—	—	—	2	1	1	2	1	1	—	—	—
	CH	35	27.3	—	—	—	—	—	—	4	6	7	11	6	1	—	—
	DH	7	27.3	—	—	—	—	—	1	—	2	1	1	—	1	1	—
	EH	4	27.2	—	—	—	—	—	—	—	1	1	2	—	—	—	—
	FH	4	27.3	—	—	—	—	—	—	—	2	—	1	1	—	—	—
	GH	2	26.8	—	—	—	—	—	—	1	—	—	1	—	—	—	—
	HH	1	28.0	—	—	—	—	—	—	—	—	—	1	—	—	—	—
	Total	62	27.1	—	—	—	—	—	4	6	12	11	18	8	2	1	—
Backcross on Florida Green Seed	AH	5	23.0	—	—	—	2	2	—	—	1	—	—	—	—	—	—
	BH	13	23.8	—	—	—	2	1	5	5	—	—	—	—	—	—	—
	CH	5	23.9	—	—	—	1	1	2	—	—	1	—	—	—	—	—
	Total	23	23.7	—	—	—	5	4	7	5	1	1	—	—	—	—	—
Backcross on Rowden	CH	1	28.0	—	—	—	—	—	—	—	—	—	1	—	—	—	—
	DH	3	27.4	—	—	—	—	—	—	1	—	1	—	—	1	—	—
	FH	5	28.3	—	—	—	—	—	—	—	—	2	1	1	1	—	—
	GH	4	27.5	—	—	—	—	—	—	1	—	—	1	2	—	—	—
	HH	5	27.8	—	—	—	—	—	—	—	—	2	1	2	—	—	—
	Total	18	27.8	—	—	—	—	—	—	2	—	5	4	5	2	—	—
Rowden parental line of backcross	CR	3	29.6	—	—	—	—	—	—	—	—	—	—	1	1	1	—
	DR	10	29.8	—	—	—	—	—	—	—	—	—	2	—	8	—	—
	ER	3	27.3	—	—	—	—	—	—	—	1	1	—	1	—	—	—
	GR	1	27.7	—	—	—	—	—	—	—	—	—	1	—	—	—	—
	Total	17	29.2	—	—	—	—	—	—	—	1	1	3	2	9	1	—

*See page 384 for explanation of letters.

nearer the shorter parent, and in the last case shorter than either parent. In crosses of a variety having ⅞-inch fiber with nine varieties ranging from $1\frac{3}{16}$- to 1½-inch fiber, seven of the F_1's had fiber shorter than that of the longer parent and two F_1's the same length as the longer parent. In a cross of a plant with 1½-inch fiber with a plant

TABLE 2.—*Length-uniformity index from a study of a Florida Green Seed × Rowden cross.*

Plant groups	Seed fuzz color grade*	Number of plants	Average of length-uniformity index	Length-uniformity index frequency by class intervals										
				79	80	81	82	83	84	85	86	87	88	89
Florida Green Seed, parental line	AH	18	83.1	—	—	1	4	10	1	1	1	—	—	—
	BH	5	82.5	—	—	1	—	4	—	—	—	—	—	—
	Total	23	83.0	—	—	2	4	14	1	1	1	—	—	—
Rowden, parental line of F_1	CR	19	85.6	1	—	1	2	—	1	2	4	4	2	2
F_1 generation	CH	19	83.4	1	1	—	3	3	6	3	1	1	—	—
	DH	3	82.0	—	1	—	1	—	—	1	—	—	—	—
	Total	22	83.2	1	2	—	4	3	6	4	1	1	—	—
F_2 generation	AH	1	85.9	—	—	—	—	—	—	—	1	—	—	—
	BH	8	82.5	—	1	—	3	2	2	—	—	—	—	—
	CH	35	83.9	—	1	2	4	3	12	11	1	1	—	—
	DH	7	84.1	—	—	—	—	2	2	3	—	—	—	—
	EH	4	83.6	—	—	—	—	2	2	—	—	—	—	—
	FH	4	84.2	—	—	—	—	2	1	—	1	—	—	—
	GH	2	83.9	—	—	—	—	—	2	—	—	—	—	—
	HH	1	85.4	—	—	—	—	—	—	1	—	—	—	—
	Total	62	83.8	—	2	2	7	11	21	15	3	1	—	—
Backcross on Florida Green Seed	AH	5	83.5	—	—	—	1	2	—	2	—	—	—	—
	BH	13	83.3	—	—	1	2	4	5	1	—	—	—	—
	CH	5	83.0	—	—	—	2	2	1	—	—	—	—	—
	Total	23	83.3	—	—	1	5	8	6	3	—	—	—	—
Backcross on Rowden	CH	1	83.1	—	—	—	—	1	—	—	—	—	—	—
	DH	3	83.2	—	—	1	—	1	—	1	—	—	—	—
	FH	5	83.4	—	—	—	1	1	2	1	—	—	—	—
	GH	4	84.8	—	—	—	—	2	—	1	—	—	1	—
	HH	5	83.5	—	—	—	1	1	2	1	—	—	—	—
	Total	18	83.7	—	—	1	2	6	4	4	—	—	1	—
Rowden parental line of backcross	CR	3	83.4	—	—	—	1	1	—	1	—	—	—	—
	DR	10	84.4	—	—	—	2	2	2	1	2	—	1	—
	ER	3	85.3	—	—	—	—	—	—	2	1	—	—	—
	GR	1	82.3	—	—	—	1	—	—	—	—	—	—	—
	Total	17	84.3	—	—	—	4	3	2	4	3	—	1	—

*See page 384 for explanation of letters.

having $1\frac{3}{16}$-inch fiber, the F_1 length was nearer that of the longer parent.

Thadani (12), in 1925, reported three crosses in upland varieties. Each of the three long parents had a staple length of $1\frac{7}{16}$ inch and the three short parents ⅞ inch. The three F_1's were shorter than the longer parent by $\frac{3}{16}$, 4/16, and $\frac{5}{16}$, respectively.

Brown (1), in 1938, reported intensified lint length in the F_1 of a cross of two upland varieties, Trice and Mebane Triumph. The staple was ⅛ inch longer than that of either parent.

Fyson (3), in 1908, and Kottur (9), in 1923, reported studies of fiber length in Asiatic cotton. Fyson (3) studied length of lint in several crosses among species of cotton of India. The cross to which he gave most attention was Jowari (*G. herbaceum*)×Jari (*G. neglectum*) which showed that length and fineness of lint were dominant over short and rough woolly lint. Kottur (9) studied a cross of the same two species but used other varieties. His cross was Dharwar No. 1 (*G. herbaceum*)×Rosea (*G. neglectum*). Length of lint was practically dominant in the F_1 or about as long as the former or longer parent. The subsequent generations segregated but not in accordance with any definite ratio.

In this review of fiber length study, particularly within the upland species, much diversity in the F_1 results is shown. As previously sugested these variations may be due partly to genetic impurity of the material used and to some extent to difficulties in obtaining accurate measurement of the fiber length by the improvised methods that probably were used. Differences in soil moisture which may have obtained in some of these cases is a factor in influencing fiber length. The fiber length results in this paper are believed to represent about as accurate a test of genetic relationships in upland cotton as could be had, for the following reasons: The parental material had been self-pollinated a sufficient number of generations to reduce it to a high degree of homozygosity. Comparison of parental material with the F_1, F_2, and backcross generations was with about as closely related plants as possible. Progenies of the actual parents employed in the crosses were used, that is, no sibs of parental plants that did not enter some cross were included. All generations were grown the same year and in close proximity, that is, within a comparatively small, uniform area of the field used. The fibrograph, which is a highly accurate measuring device for lint length, was employed.

RELATION OF SEED FUZZ COLOR AND FIBER LENGTH

Since the Florida Green Seed had very short lint along with the intense green seed, it was of interest to check whether this condition was a coincidence or genetic association. In the F_2 generation there is an appearance of genetic association as shown in Table 1. The scatter diagram effect of the frequencies and the averages of the *upper-half mean* indicate that as the seed fuzz becomes less green the fiber is somewhat longer. There is also a slight tendency of this sort shown in the progeny of the backcross on Florida Green Seed. The

number of plants in some of the frequencies of this F_2 and backcross, however, is too small to warrant definite conclusions as to the relationship.

FIBER LENGTH UNIFORMITY

Fiber length variation within the plants of the 1940 growth of this study as expressed by the *length-uniformity index* and given in frequency distributions is shown, as heretofore stated, in Table 2. As in the case of the *upper-half mean* length shown in Table 1, this index is given also in frequencies for each plant group and for each seed fuzz color grade within these groups. It has already been pointed out that the *length-uniformity index* was highest within the plants of the Rowden parental lines, lowest in the plants of the Florida Green Seed lines, and at an intermediate level between these parents for the F_1 generation. The Rowden parental lines and F_1, however, showed more frequency spread for the value than the Florida Green Seed parental lines.

The averages of the plant *length-uniformity index* for the F_2 and backcross groups were at about the same level of that for the F_1 generation. The frequency range in the F_2 practically coincided with that of the F_1, while the backcross ranges were somewhat less. There was little difference in the average of this index and its frequency range between the two backcross groups. While there is some less length uniformity in the plants of the Florida Green Seed than in the Rowden plants, no association of seed fuzz color and length uniformity appears to occur in the F_2 and backcross generations. The point of chief interest in Table 2 is that considerable variation in *length-uniformity index* occurs from plant to plant in all the groups. These differences, however, may be no more than that expected in any group of cotton plants.

SUMMARY AND CONCLUSIONS

The F_1 and F_2 generations and first generation backcrosses were grown from a Florida Green Seed and Rowden cross. The parental lines were also grown along with these hybrid groups. The F_1 generation was repeated the second year so that all groups under study could be compared in the same season. The Florida Green Seed stock had intense green seed fuzz and very short staple (¾ inch), while the Rowden stock had white seed fuzz and intermediate staple length ($1\frac{1}{32}$ inch). Seed fuzz color standards were made up and used in placing the plants of the several groups in classes according to shade of fuzz color possessed. The fiber length was determined by the Hertel fibrograph and the *length-uniformity index* computed from the two fibrograph determinations, the *mean* and the *upper-half mean*.

The plants of the F_2 generation varied for fuzz color across the entire range of the green fuzz color standards of eight grades, that is, from intense green like the Florida Green Seed parent to a mere vestige of green hairs in the fuzz mat. No F_2 plants with seed as white as those in the Rowden fuzz color scale segregated. In the backcross to Florida Green Seed the seed fuzz grades consisted of three, the two parental grades and the greener of the two F_1 grades. In the

backcross to the Rowden, the seed fuzz grades consisted of five, the two F_1 grades and the last three found on the light side of the F_2 scale. Discontinuous of modal segregation was not shown for fuzz color in the segregating generations. However, the F_1 range was quite narrow and exhibited a case of dominance of this color which was not entirely complete.

Some slight association was shown between fuzz color and length of fiber in the F_2 and backcross to Florida Green Seed groups. The greener seed fuzz color grades had slightly shorter fiber.

The length of fiber was incompletely dominant in the F_1 and showed monomodal distribution in the segregating generations. The Florida Green Seed recurrent parent in the backcross tended to reduce the length of fiber below that of the F_1, but the Rowden recurrent parent did not pull the length in that backcross above the F_1. The particular Rowden plant in this case, although a progeny of the original parent plant, was slightly shorter in fiber length.

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THE EFFECT OF SURFACE MULCHES ON WATER CONSERVATION AND FORAGE PRODUCTION IN SOME SEMIDESERT GRASSLAND SOILS[1]

E. L. Beutner and Darwin Anderson[2]

STUDIES of the effects of surface mulches, condition of soil surface, and different types of plant cover on runoff and soil loss have received considerable attention in various parts of the country during the last few years. The benefits of mulches to infiltration have been demonstrated especially in agricultural lands of the Great Plains, where successful growth of many farm crops depends on conservation of as much as possible of the rather limited rainfall. In recent work in Ohio, Borst and Woodburn[3] have analyzed the mechanics of the action of mulches in controlling erosion and determined the relative importance of raindrop impact and overland flow. The pore-clogging effect of rain-dispersed soil particles has been known for some time, although details of just how this action takes place were not fully investigated until recently.

Obviously, the approach to this problem differs between soils that are cultivated and those that comprise range lands which are used for grazing. The benefits of natural plant litters have been observed by soil conservation workers and range ecologists. Little work has been done in the past, however, to determine their actual effectiveness in promoting infiltration of water into range-land soils and the part they may play in restoring vegetation in areas which have suffered from poor land use and accelerated erosion. It is fairly clear that a cover of vegetation tends to retard the rate of surface runoff and provides stability against erosion. It is not generally recognized, however, how plants and soils under natural conditions are dependent upon one another to maintain this condition. Stripping the protective cover from the soil apparently brings about other changes than simply removing a mechanical surface and sub-surface obstruction to accelerated runoff and erosion. In most soils (the very sandy and gravelly ones being not so greatly affected), when the surface is laid bare to the influence of torrential rains through lack of permanent cover, it is not long before the natural vegetal litter, mulch, and organic matter disappear. This removes the buffer protection and the soil then seals over so that water penetrates with difficulty, thus giving rise to a more or less permanent droughty condition. Unless this surface condition is changed, it is not surprising that natural revegetation is very slow, even when grazing pressure or other detrimental factors are removed.

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[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture. Tucson, Ariz. Received for publication December 16, 1942.

[2]Project supervisor and Assistant Range Ecologist, respectively, Office of Research, Soil Conservation Service, Cooperating with the Arizona Agricultural Experiment Station.

[3]Borst, H. L., and Woodburn, Russell. The effect of mulching and methods of cultivation on runoff and erosion from Muskingum silt loam. Agr. Engin., 23:56–60. 1942.

One project of the Soil Conservation Service in cooperation with the Arizona Agricultural Experiment Station has to do with investigation of infiltration characteristics of some Arizona soils,[4] especially as related to development of methods of soil and water conservation. These studies to date have been on uncultivated soils, which are or have been covered with natural vegetation that is used for grazing.

DETAILS OF STUDY SITES AND EXPERIMENTAL DATA

Small plots, each 6 by 12 feet in size, were established on two widely different soils. One soil occurring at 3,700 feet elevation on the Page-Trowbridge Experimental Ranch is an upland sandy clay loam with a heavy clay subsoil and is classified in the Continental series. Under normal conditions it supports a good growth of perennial grasses, including several gramas, Aristida, and other species typical of the semidesert grassland. The other soil is an alluvial silty clay loam occurring adjacent to the Santa Cruz River near Tucson at an elevation of 2,200 feet and is classified in the Pima series. Under natural conditions this soil supports swale grasses, such as tobosa and the sacatons, as well as various types of shrubby or browse vegetation. When irrigation water is available, it is an important agricultural soil.

When the study was initiated, the upland soil was covered with a fair stand of grama grass and annual spring-growing plants, while the alluvial soil was practically bare owing to severe sheet and gully erosion during recent years. Because of widely different soil and cover conditions in the two sites, results of the first year's study will be considered separately for each site.

UPLAND SOIL

When plots were established on the upland soil, all of the perennial vegetation was clipped to the ground level and the surface litter, consisting of vegetal debris, was carefully removed by hand so that initial surface conditions on all plots were similar. Provisions were made at the lower end of each plot for catching surface runoff resulting from natural rains. The plots were also designed so that rain could be applied artificially in controlled amounts and intensities.

One set of plots was then covered with a light mulch (approximately 2 tons per acre) of cut grass, another set with a similar mulch of native annual vegetation consisting chiefly of alfilaria and Indian wheat. In a third set of plots chopped grass was mixed in the upper 3 inches of soil, while in the fourth set chopped alfalfa hay was mixed with the soil. Check plots consisted of one set in which the upper 3 inches of soil was mixed without addition of organic materials and one in which the soil was undisturbed and no surface mulch was added. These plots were established during the late spring dry season when soil moisture was low and uniform in all plots. To study initial per-

[4]BEUTNER, E. L., GAEBE, R. R., and HORTON, R. E. Sprinkled plot runoff and infiltration studies on Arizona desert soils. Trans. Amer. Geophys. Union, 550–558. 1940.

formance, an application of artificial rain was made for 1 hour at a rate of approximately 1.75 inches per hour. The effect on water intake of the various treatments is outlined briefly in Table 1.

TABLE 1.—*Effect of surface mulches and of incorporated organic matter on water intake.**

Treatment	Rainfall intensity per hour, inches	Runoff, inches	Water loss, %
Grass straw mulch	1.80	0.350	19.5
Alfilaria mulch	1.80	0.382	21.2
Grass straw mixed with soil	1.76	1.183	67.2
Alfalfa mixed with soil	1.76	1.090	61.9
Soil mixed	1.78	1.200	67.3
Untreated	1.78	1.104	61.9

*Rainfall was applied for an hour on each plot.

It is apparent that intake of water was much greater on the surface mulched plots than on any of the others. In fact, all the plots which had bare surfaces reacted similarly as far as infiltration is concerned. While two treatments consisted of incorporating chopped grass straw and alfalfa into the surface 3 inches of soil, only a part of this material remained on the surface and as a result the soil surface was bare and conditions were similar to those on the mixed soil and the untreated plots. No further artificial rainfall was applied to these plots in 1941. However, runoff, which occurred from natural rains, was measured through the summer of 1941.

The mixed soil plots were kept free of plant growth and during the summer rainy period infiltration under bare surface conditions remained rather low. On the other three types of plots natural perennial vegetation, which originally had been clipped to the ground level, was allowed to resume normal growth and new seedlings became established. By the end of the summer they reached maturity and produced seed. Fig. 1 shows the condition of the mulched and unmulched plots at the end of the 1941 summer growing season Runoff losses during the summer of 1941 are briefly outlined in Table 2.

TABLE 2.—*Runoff losses on mulched and unmulched plots, summer of 1941.*

Treatment	Rainfall, inches*	Runoff, %
Check plot (bare)	6.15	57.4
Check plot (Rothrock's grama grass cover—no mulch)	6.15	31.0
Rothrock's grama cover and alfilaria mulch	6.15	13.0
Rothrock's grama cover and grass mulch	6.15	9.2

*Represents summer rainfall, July–Oct., 1941.

An interesting point here is that while the grass plot without mulch lost only 20% more water than the average of the mulched plots, it produced less than half the number of plants and volume production

of forage than did the mulched plots. Apparently, an increase of effective rainfall or infiltration by 20% may result in doubling the forage production. This is a reasonable conclusion in areas such as this where annual rainfall seldom exceeds 15 inches and where the climatic conditions under which plants grow are rigorous.

ALLUVIAL SOIL

On the City Farm site which is typical of denuded alluvial flat areas in southern Arizona which were formerly occupied by grass stands, the effect of mulches on infiltration is even greater than was the case on the Page-Trowbridge Ranch. The soil here is a silty clay loam containing considerable alkali, and under bare, undisturbed conditions its ability to take up water is almost *nil*. Hydrographs of runoff for bare and grass-mulched plots are shown in Fig. 2. Total water loss on the unmulched plots as a result of application of 1.75 inches of rain in an hour was 1.27 inches or 72% of the rainfall as compared to 0.50 inch or 28% of the rainfall from the plot covered with grass straw.

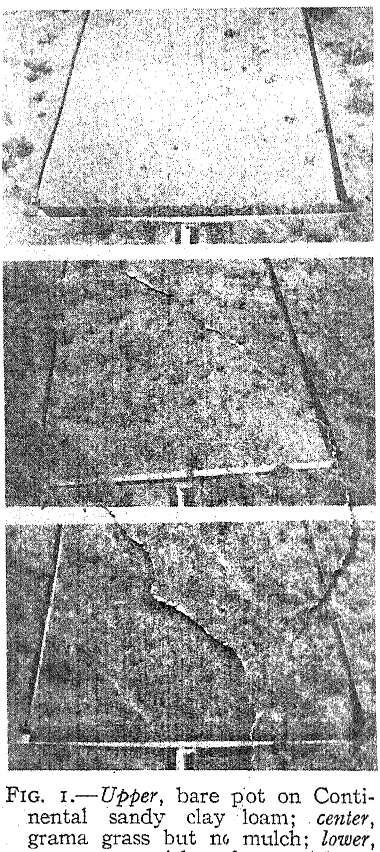

FIG. 1.—*Upper*, bare plot on Continental sandy clay loam; *center*, grama grass but no mulch; *lower*, grass cover with surface mulch.

While the grass straw mulch was most efficient in affording soil protection and aiding infiltration in the early stages of the study, it remained fairly effective for a year after its application. During the period July 1941 to March 1942, which included intense summer rains as well as light winter rains, the untreated plots lost as runoff 7.05 inches or 73% of a total rainfall of 9.66 inches, while the grass straw mulched plots lost only 1.02 inches or 11% of the rainfall.

The significance of surface mulches in promoting intake of water in these heavy-textured soils is apparent and, where natural rainfall only need be considered, results may be applied directly to field problems. Under irrigated conditions, further field tests are necessary in order to determine relationships with other cultural practices.

DISCUSSION AND CONCLUSIONS

Conservation of moisture is absolutely necessary if desirable forage grasses are to maintain a more or less complete ground cover and

furnish maximum forage for grazing. Rainfall effectiveness, or the amount of water that enters the soil and is available for plant growth, rather than the total amount of rain that falls is the determining influence in maintaining an adequate plant cover. Under climatic conditions existing in the semidesert grassland, average rainfall is sufficient to support an adequate grass cover only where the character

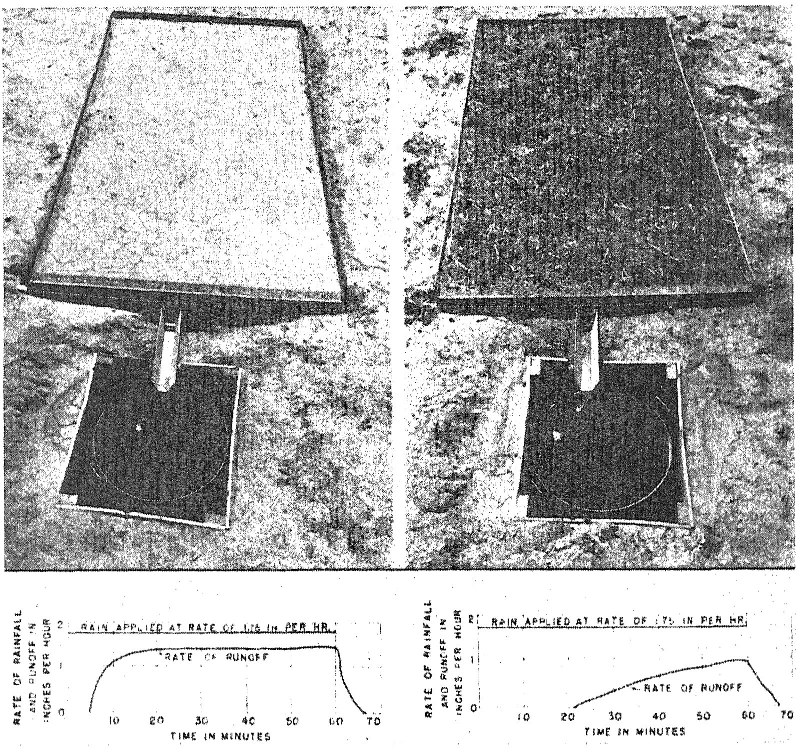

FIG. 2.—Plots with and without mulch and hydrographs of runoff.

of the soil surface is favorable for ready infiltration of water into the soil. Even under the most favorable conditions, grass is seldom able to maintain a dense sod cover except in swales or other areas where additional moisture is received by runoff from adjacent slopes.

If grasses are conservatively grazed so that part of each year's volume growth is allowed to remain for reserve feed and soil protection, those portions of the soil surface not directly covered by plants are fairly well protected by plant debris and litter which is just as effective as the plants themselves in promoting infiltration and controlling erosion. If, on the other hand, the vegetation is utilized so heavily that plants are grazed nearly to the ground level each year, it is apparent that no mulch or litter will be added to the soil surface, much bare soil will be exposed, sheet erosion will be intiated, and

runoff will increase. Rainfall effectiveness then decreases and only during years of above-normal precipitation are adequate amounts transmitted into the soil. Under these conditions there is a deficiency or drought during most years with a consequent decline in vigor and density of the grass cover as well as in the volume of forage produced.

Figs. 3 and 4 offer practical evidence of the close relationship existing between plant cover and surface litter and conservation of water and soil. In the half section of land comprising the Page-Trowbridge Experimental Ranch, conservation measures, including limited

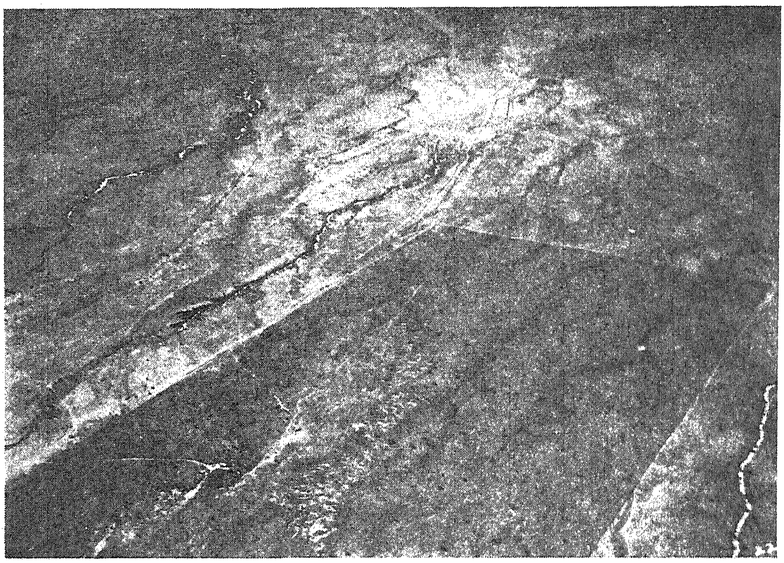

FIG. 3.—Airplane view of Page-Trowbridge Experimental Ranch. Infiltration of rainfall into the soil is nearly complete. In mismanaged range outside plant cover and litter are sparse, runoff is high, and erosion is active.

grazing, have been practiced for the past 18 years. As a result a good grass cover has been built up, patches of soil between plants are covered with plant litter and almost all of the rainfall soaks into the soil. Nearly all of the old gullies have healed and the area is stabilized. In the surrounding range land, however, grazing has been limited only by available forage which has declined steadily so that only remnants of palatable grasses remain, while unpalatable shrubs have increased. Runoff is high and sheet and gully erosion are active.

Frequently, in attempting to rehabilitate deteriorated and eroding range areas, it is possible to use annual vegetation in such a way that it will supply litter which aids in re-establishment of desirable perennial grasses. Thus, in southern Arizona, such plants as alfilaria, Indian wheat, and other winter and spring-growing annuals may have greater value if they are allowed to remain on the soil, at least in part, than if they are fully grazed. They offer little competition for moisture,

since they mature several months before most perennial grasses resume growth with the advent of summer rains. The mulch which they furnish is very effective in promoting infiltration and controlling erosion, thus providing favorable conditions for establishment and growth of perennial grasses. Where existing plants cannot be used for

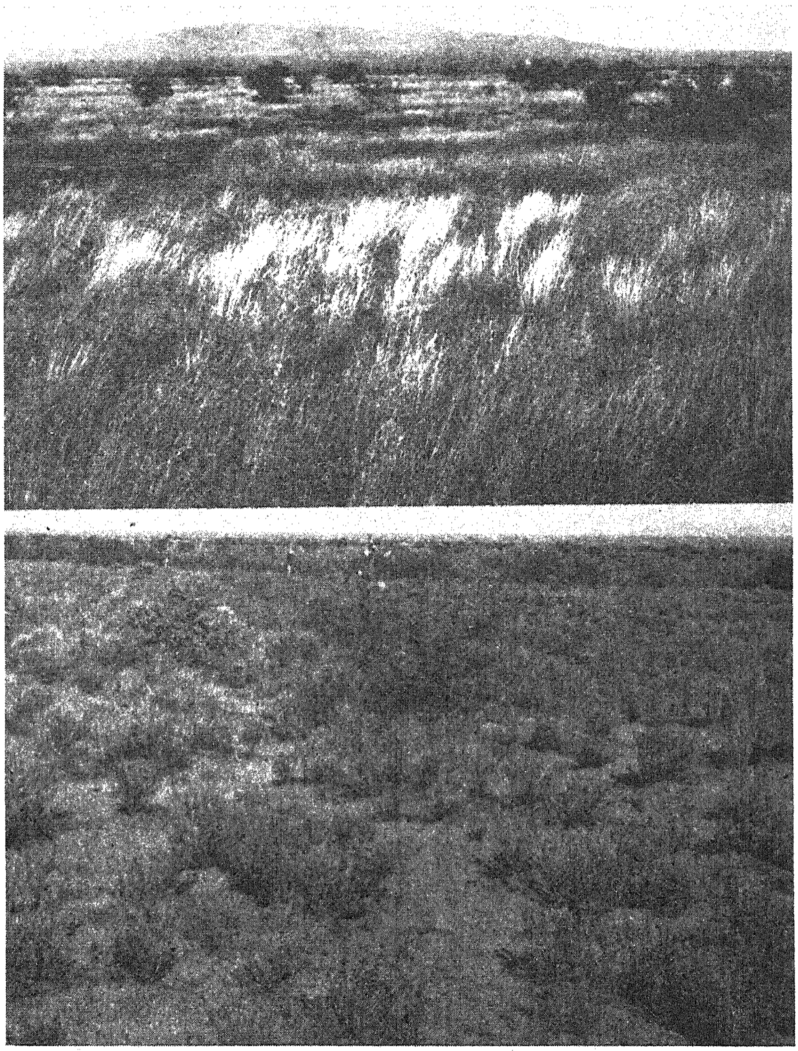

FIG. 4.—*Above*, view on experimental ranch where grass and litter form a good cover. Forage is produced for at least 15 head of cattle per section on a sustaining basis. *Below*, mismanaged range adjacent to experimental ranch. Grass has been largely replaced by shrubs. Forage produced supports only a few head of cattle per section on a declining basis.

mulch or where growth of annuals is sparse, it is often possible to add straw or other vegetal debris in areas that are being reseeded.

The importance of surface mulches in conserving water and soil cannot be overemphasized. Their maintenance should, wherever possible, be part of the range-management plan. They offer one of the most effective soil and water conservation measures and are more economical than many other artificial methods.

SUMMARY

Results of small plot studies conducted on two soil types near Tucson, Ariz., are outlined. Various types of vegetal materials were used as surface mulches and incorporated into the soil. Their effects on infiltration were evaluated by means of measuring runoff secured from artificial application of rain and by collecting runoff resulting from natural rains.

It was found that protection of the soil surface either by plants themselves or by organic litter which they furnish prevents sealing of the soil and is of utmost importance in promoting infiltration of water into the soil and conserving moisture for plant growth. In areas of low rainfall, maximum conservation of water is essential if adequate forage production is to be expected. A 20% increase in conservation of moisture in well-vegetated areas may easily increase forage production by 50%. Where plant cover is sparse, conservation of moisture aids in increasing plant density and may increase total forage production many fold.

THE BORON CONTENT OF CERTAIN FORAGE AND VEGETABLE CROPS[1]

R. I. MUNSELL AND B. A. BROWN[2]

SINCE boron deficiency symptoms in alfalfa were reported by the Storrs, Conn., Experiment Station in 1939 (2, 3),[3] investigations have been expanded to include other crops and soils. Boron studies on alfalfa now include tests on outlying farms to determine the effect of soil type differences on response of alfalfa to boron. A number of vegetable crops and such forage crops as mangels, soybeans, and cereals for hay have been included in a test of the response of crops to treatment with borax and different rates of liming. To study the effect of overliming on boron availability, a series of pot experiments were set up and soybeans and alfalfa grown as indicator crops.

In addition to the field and pots studies, considerable laboratory work has been done in determining the boron content of the crops grown and the soils used in these experiments. The method of Berger and Truog (1) for the estimation of total boron in plants and "available" boron in soils was used. In using this method of analysis for plant material, it is necessary to vary the weight of sample so that the color which is developed for the final reading will be within the limits of the standards. It was soon found that the boron content varied not only with different crop plants but with different parts of the same plant. Furthermore, variations in rate of application of borax and limestone were reflected in the boron content of the plant. As a result, exploratory analyses were required whenever a new type of plant material was analyzed. Since very few data which illustrate these differences are available, it was felt that it would be helpful to publish the results of certain boron analyses which exemplify such variations. These data should be useful in estimating in advance the probable boron content of a number of crops.

EXPERIMENTAL

In Table 1 are given the results of an experiment (10) carried out in 1940 in which a number of crops were grown with and without borax and at moderate and heavy rates of liming. The soil used for this test is Merrimac loamy sand with a pH before liming of 5.2 and an available boron content of 0.25 p.p.m. Previous to planting, 40% superphosphate and 60% muriate of potash were each applied at 200 pounds per acre. In addition, the oats and barley received 100 pounds of calnitro. With the exception of soybeans which received no nitrogen, all the other crops were treated with calnitro at 200 pounds per acre.

In the following discussion of Table 1, the soybean is treated separately since it was analyzed in more detail. Of the other crops

[1]Contribution from the Department of Agronomy. Storrs (Conn.) Agricultural Experiment Station, Storrs, Conn. Received for publication December 17, 1942.

[2]Research Assistant and Associate Agronomist, respectively. Many of the analyses reported in this paper were made by M. T. Vittum and Maurice Fried, formerly Graduate Assistants.

[3]Figures in parenthesis refer to "Literature Cited", p. 408.

listed in Table 1, spinach has the highest boron content and the two cereals the lowest. The remaining crops occupy an intermediate position, varying over a rather narrow range. Cook and Millar (4) report analyses of spinach showing that the untreated leaves contained only 5 p.p.m. and when borax was applied at 20 pounds per acre, 15 p.p.m. At the same time the untreated roots contained 5 p.p.m. and treated roots 11 p.p.m. These results are much lower than those obtained at Storrs, Conn. A possible explanation lies in the fact that definite deficiency symptoms were noted in the Michigan experiments. No deficiency symptoms were evident at Storrs, al-

TABLE 1.—*Boron content of certain vegetable and forage crops as influenced by application of borax and limestone.**

Crop	Boron content, p.p.m.†			
	Dolomitic limestone at 2 tons		Dolomitic limestone at 4 tons	
	No borax	20 pounds of borax per acre	No borax	20 pounds of borax per acre
Carrots: Tops	20	41	20	34
Roots	26	36	21	38
Turnips: Tops	18	40	15	45
Roots	19	29	17	28
Lettuce: Leaves	17	30	13	28
Roots	17	19	11	19
Spinach: Leaves	53	121	26	109
Roots	31	34	22	34
Tomatoes: Fruit	22	36	18	25
Leaves	24	49	21	48
Cabbage: Heads	16	33	11	28
String beans: Pods (1st picking)	25	40	23	35
Pods (2nd picking)	24	35	22	28
Leaves	20	62	20	62
Mangels: Tops	19	55	18	58
Roots	22	28	23	31
Oats: Cut for hay; grain in milk	2	7	4	7
Barley: Cut for hay; grain in milk	5	15	4	12
Soybean: Leaf blade	38	144	34	142
Leaf petiole	22	42	24	46
Plant stem	9	15	8	13
Seed (without pod)	18	34	14	33

*Merrimac loamy sand ("available" boron content of untreated soil is 0.25 p.p.m.).
†Results are averages of duplicate plots. All determinations were run in duplicate on moisture-free material.

though the yield of spinach was increased by the addition of borax. Cook and Millar do not give the amount of "available" boron in the Thomas sandy loam soil used in their experiments, but state that it is an alkaline soil high in organic matter and known to be deficient in boron available to sugar beets. This indicates that the Merrimac loamy sand was higher in "available" boron content originally than the Michigan soil.

McHargue, *et al.* (6) report the boron content of spinach as 31.5 p.p.m. This crop was presumably grown without borax treatment. Whether the leaves or the whole plant were analyzed is not indicated.

At Storrs, barley and oats cut for hay were very low in boron, although slightly higher than the maximum of 2 p.p.m. reported by McHargue (7) and Lohnis (5).

With the single exception of spinach, an increase from 2 to 4 tons in the rate of application of limestone had very little effect on the amount of boron found in the plant. This was true whether the plots did or did not receive borax. The boron requirements of the spinach plant were so high that doubling the limestone application prevented it from securing a normal amount, particularly on the plots receiving no borax. Except in the case of mangels and spinach, the amount of available boron in this Merrimac soil was above the critical point for the crops grown in this experiment, even when rather heavily limed. Further evidence pointing to this conclusion lies in the fact that the available boron in the soil receiving 4 tons of limestone was not decreased below the amount present in the untreated soil at the start of the experiment.

The boron content of various parts of the soybeans are given in Table 1 as an example of the wide differences encountered in the different parts of certain plants. It is evident that by far the greatest concentration of boron in the soybean occurs in the leaf blade and the least in the stem, with the petiole intermediate. These results follow closely the averages published by McHargue (7) for a number of plants when the leaves, petioles, and stems were analyzed separately. Scofield, *et al.* (9) in working with sunflower seedlings concluded that for determining the available boron in a soil, sunflowers should be grown and the leaves analyzed since they reflect differences in the boron concentration of the soil solution more markedly than other parts of the plant. This same observation can be made in the case of the soybean. Here again, doubling the rate of liming made no difference in the amount of boron found in the plant.

POT EXPERIMENTS

In the spring of 1940, a series of pot cultures were set up outdoors using Charlton fine sandy loam soil and soybeans as an indicator crop. The same pots of soil were planted with soybeans again in 1941. As a basic treatment, the soil in all pots received both P_2O_5 and K_2O at the rate of 100 pounds per acre. Plant analyses, together with borax and hydrated lime treatments for 1940 and 1941, are given in Table 2.

In this pot experiment, serious over-liming injury to the soybeans was noted in both years wherever the 4-ton rate of liming was used.

The application of borax at 20 pounds did not alleviate this injury. The boron contents of the leaves harvested in 1940 declined gradually as the rate of liming increased. The high boron contents of the leaves from treatment No. 3 may have been partially due to the relatively smaller growth of that culture. In general, however, there was a marked drop in boron content of the leaves where no borax had been applied and also in most cases where only 10 pounds had been used.

ALFALFA ON MERRIMAC FINE SANDY LOAM SOIL

In August, 1939, a series of small plots were seeded with Grimm alfalfa on Merrimac fine sandy loam and given various fertilizer treatments, each with and without borax. Two harvests were made in both 1940 and 1941 and samples of pure alfalfa analyzed for boron (Table 3).

In this experiment, plots not treated with borax contained an average of 26 p.p.m. of boron. This figure is not greatly different from the average of 33 p.p.m. reported by McHargue. An application

TABLE 2.—*Effect of the application of hydrated lime and borax on the boron content of the leaf, stem, pod, and root of the soybean.**

Treatment No.	pH Nov., 1940	Treatment of soil, pounds per acre				Boron content, p.p.m.	
		Hydrated lime		Borax			
		1940	1941	1940	1941	1940	1941
			Leaves				
1	4.86	0	0	0	0	83	51
2	4.90	0	8,000	10	0	118	63
3	4.85	0	8,000	20	0	148	164
4	6.38	4,000	0	0	0	74	25
5	6.62	4,000	4,000	10	0	95	78
6	6.60	4,000	4,000	20	0	115	119
7	7.48	8,000	0	0	0	62	30
8	7.63	8,000	0	10	0	80	95
9	7.58	8,000	0	20	0	72	96
			Pods, Including Seeds				
4	6.38	4,000	0	0	0	—†	26
6	6.60	4,000	4,000	20	0	—	45
			Stems				
4	6.38	4,000	0	0	0	—	27
6	6.60	4,000	4,000	20	0	—	38
			Roots				
7	7.48	8,000	0	0	0	—	14
9	7.58	8,000	0	20	0	—	16

*Charlton fine sandy loam soil. The "available" boron content of untreated soil is 0.50 p.p.m.
†Analyses not available for 1940 crop.

TABLE 3.—*Boron content of alfalfa under different fertilizer treatments on Merrimac fine sandy loam.**

Treatment†	1940 cuttings, p.p.m.		1941 cuttings, p.p.m.		Average of four cuttings, p.p.m.
	First	Second	First	Second	
LPK	31‡	20	19	27	24
LPKB	44	39	44	38	48
LLPK	33	24	24	28	27
LLPKB	46	45	39	39	42
LPKK	29	23	25	34	28
LPKKB	54	44	37	47	46

*"Available" boron content of untreated soil is 0.45 p.p.m.
†L = Dolomitic limestone at 4 tons per acre; P = 48% superphosphate at 200 pounds per acre; K = 60% muriate of potash at 200 pounds per acre; B = borax at 20 pounds per acre.
‡Average of duplicate samples from duplicate plots.

of 20 pounds of borax increased the boron in the alfalfa an average of 73%. Doubling the rate of application of limestone did not decrease appreciably the boron content of the alfalfa.

The boron analyses of a few miscellaneous crops are brought to-

TABLE 4.—*Boron analyses of miscellaneous crops on Charlton fine sandy loam soil.**

Crop	Stage of growth	Special treatment	Number of samples	Boron content, p.p.m.	
				No borax	20 pounds of borax per acre
Ladino clover, 1940	8–10 in.	None	3	30	32
Ladino clover, 1941	8–10 in.	None	4	28	30
R. I. bent grass, 1940	3.5 in.	Calnitro to give 84 lbs. of N	5	15	—
R. I. bent grass, 1941	3.5 in.	Sulfate of ammonia to give 84 lbs. of N	4	9	—
Orchard grass, 1940	Third cutting	None	3	13	18
Timothy, 1940	Pre-bloom	Calnitro at 150 lbs. in April and after each cutting	1	16	—
Timothy, 1940	Rowen, 6–8 in.		4	10	—
Lancaster Sure Crop corn, 1941	Silage, kernels in dough	300 lbs. of sulfate of ammonia	2	12	—
Alfalfa, Sept. 11, 1940	New shoots after 3d cutting on Sept. 5, 1940	None	2	61	69
Alfalfa roots, Sept. 11, 1940	Same plants as above	None	2	28	39

*"Available" boron content of untreated soil is 0.50 p.p.m.

gether in Table 4. All crops received adequate applications of limestone, superphosphate, and potash at time of seeding. Special treatments are indicated in the table.

These data place Ladino clover on the same level as alfalfa in boron content, and the grasses intermediate between the legumes and cereals, shown in Table 1.

In Table 5 the boron content of alfalfa which showed boron-deficiency symptoms is compared with that of normal alfalfa.

TABLE 5.—*Analyses of boron-deficient and normal leaves and stems of second cutting alfalfa on Charlton fine sandy loam in 1939.*

Plot No.	Treatment	Percentage of yellowed plants	Boron content, p.p.m.	
			Leaves	Stems
C2Sd	No borax	75	23	15
C3Sb	Borax at 20 lbs. per acre	1	63	24

While both the alfalfa leaves and stems increased in boron content when borax was applied, the leaves showed a much greater increase. The application of borax prevented almost entirely the yellowing of the plants.

McLarty, *et al.* (8) report from British Columbia on the difference in boron content between yellowed, stunted alfalfa and normal green plants. They found 7 p.p.m. of boron in the yellowed plants and 29 p.p.m. in the normal alfalfa.

DISCUSSION

On the basis of boron content, the data presented in this paper show that the crops analyzed fall into a few general groups. At the bottom of the scale are the cereals and then with increasing boron content follow the grasses, the vegetables, and such root crops as mangels and turnips and then the legumes. In our experiments, spinach has been an exception in that it has analyzed even higher in boron than the legumes.

Table 6 is offered as a guide in determining the size of sample that should be used in analyzing plant material of various types for boron. Rather than take a sample of less than 0.2 gram, it is preferable to dissolve the soluble plant ash in a larger amount of acid.

TABLE 6.—*Suggested size of sample to use in analyzing plants of varying contents of boron.*

Boron range, p.p.m.	Weight of sample, grams	Amount of acid to be added to plant ash, cc
0–10	1.0	5
5–15	0.8	5
10–30	0.5	5
15–40	0.4	5
20–50	0.2	5
Over 50	0.2	10

In the various *field* experiments here reported, doubling the rate of liming has not produced overliming injury nor appreciably reduced the boron content of the plants grown. In the case of alfalfa grown on Merrimac fine sandy loam, liming at as high a rate as 8 tons has not produced abnormal results. A determination of the buffer capacity of this Merrimac soil shows it to be higher than any of seven other soil types commonly found in eastern Connecticut. Another factor which might account for the lack of overliming injury is the fact that when the limestone was applied it was worked into the soil with a spike-tooth harrow. Consequently, most of the limestone was effective only in the upper 2 or 3 inches, while the alfalfa roots extended far below this layer.

In *pot* experiments, soybeans have shown overliming injury at the higher rate of liming on one of the three soils used. When alfalfa was grown in pots, it has shown injury at the higher rates of liming on both soils used. The explanation as to why more overliming injury was obtained in pot experiments than in the field is not clear. A contributing factor may have been the practice, in setting up the pots, of thoroughly mixing the lime with the soil throughout its depth.

Root analyses of soybeans and alfalfa show the roots to be lowest in boron content of any part of these plants. However, in the case of the vegetables, except for spinach, the leaves and roots contained about the same amount of boron.

The difficulty of comparing data from various experiment stations pertaining to boron analyses of the same crop emphasizes the importance of clearly indicating the type and fertility level of the soil, fertilizer treatment, and stage of growth or part of the plant analyzed when publishing analyses of plant material.

SUMMARY

Boron analyses are reported for alfalfa, soybeans, cereals, vegetables, root crops, and certain miscellaneous crops. Boron analyses are also presented of various parts of soybeans, vegetables, and root crops.

Of the crops analyzed, the legumes were highest in boron content, followed by root crops, all vegetables except spinach, the grasses, and finally the cereals. Spinach was the exception in containing more boron than any of the other crops.

Analyses of various parts of the soybean showed that the leaf blade was highest in boron content followed by the petiole, stem, and root.

In *pot* experiments using Charlton soil, the amount of boron in the soybean leaf declined the first year as the rate of liming increased. In the second year, the boron content decreased wherever less than 20 pounds of borax per acre was applied. In *field* experiments on the two Merrimac soils, no decrease in boron occurred in alfalfa or the vegetable and root crops when rate of liming was doubled.

Boron-deficiency symptoms have been prevented or yields increased by the application of borax at the rate of 20 pounds per acre to alfalfa, turnips, mangels, cabbage, carrots, lettuce, and spinach.

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COTTON IMPROVEMENT IN SOUTHEAST MISSOURI[1]

J. R. PAULLING[2]

RECORDS show that cotton has been grown in Missouri for more than 75 years, but only in the past 25 years has Missouri cotton taken a prominent rank among the crops of this state and in relation to the cotton crops of other states. Missouri is now producing some 400,000 acres, ranks eleventh among the 16 major cotton states in acreage but ninth in actual production. Though confined to a very small portion of the state, cotton ranks first in cash sales among the field crops of the state and is never lower than fourth in gross value.

The crop is confined to 15 counties in south Missouri with all but 1% of it found in seven southeastern counties. The region has fertile alluvial soil, is north of the boll weevil area, and is comparatively free from other insect pests and diseases.

It may be of interest to consider the main factors, aside from the rise in cotton prices, that account for the doubling in value of Missouri cotton during the past six years without appreciable increase in acreage. Table 1 gives the value of the Missouri cotton crop from 1915 to 1941, inclusive.

TABLE 1.—*Gross value of Missouri cotton, 1915–1941, inclusive.*

Year	Value	Acreage
1915	$ 2,512,000	89,000
1920	5,060,000	140,000
1925	21,568,000	530,000
1930	8,555,000	391,000
1935	12,714,000	325,000
1936	22,965,000	414,000
1937	17,214,000	569,000
1938	17,837,000	357,000
1939	23,221,000	375,000
1940	21,654,000	405,000
1941	49,204,000	415,000

The 1941 crop was not the largest nor was the price the highest in the experience of growers, yet its value was twice that of any former crop. This was due largely to the fact that growers had the best quality crop they had ever raised, to make the most of the rise in the market, and it appears that the 1942 crop will equal last year's.

From the grower's viewpoint cotton is strictly a cash crop. It is produced for only one purpose—the money it will return. Four factors usually determine how much money a cotton crop will bring, *viz.*, (1) yield, (2) staple length, (3) grade, and (4) market price. The

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first three are largely within the grower's control, with the fourth calling for group action.

In the years just preceding the most recent phase of the Missouri cotton improvement program, Missouri cotton production was marked by the following conditions: (1) The highest *yield* for so large an acreage found anywhere except where the crop was irrigated; (2) the shortest *staple* produced in the Mississippi bottom lands, as measured in percentage of the crop 1 inch or longer; (3) the poorest *grade* produced in the entire cotton belt as measured in terms of percentage equal to and better than middling; and (4) a market situation as bad as the worst. Buyers avoided Missouri cotton to such an extent that growers often hauled their crops across the state line in order to get it billed from other states. The practice of buying "in the seed" was general until 1933. While selling "in the lint" has prevailed since then, discriminations in price for differences in lint quality have been only occasional.

Improvement of Missouri's cotton industry in these four particulars has, for the last six years, been the aim of the state's entire agricultural extension program relating to cotton. Re-stated, the objectives are (1) to increase the yield, (2) to lengthen the staple, (3) to improve the grade, (4) to improve market facilities, and (5) to enhance the reputation of Missouri cotton "in the trade".

For the solution of these problems, research gives much important information but space permits mentioning here but two major principles. The variety of cotton grown has much to do with the *yield*, practically controls the *staple length*, influences the *grade* materially, and, has come, particularly in recent years, to occupy a place of importance in the mind of the *buyer*. The use of high grade seed of the chosen variety is often as important as choosing the proper variety in the first place.

The best varieties of cotton for Missouri were discovered after many years of testing on outlying experiment fields by B. M. King in the various cotton localties of the southern counties.

After the development of this program with the aid of growers and ginners, the work of improvement has been advanced vigorously by every means available to the agricultural extension worker. These include meetings, demonstrations, tours, experiment field meetings, personal contacts, publicity, utilization of the government classing service, gin surveys, and annual 3-day tours to the ginning laboratory at Stoneville, Miss., and nearby plantations of cotton breeders. Ginners have assumed the lead in providing good seed of the proper varieties, both reasonably and conveniently. For several years they have bought from 400 to more than 500 tons of breeder seed, multiplied this seed in such manner as to preserve its purity, and distributed it in a quantity equal to that required to plant the entire crop with seed not more than one year removed from the breeder. The State Seed Improvement Association has played an important part in providing a pattern for multiplying high-quality seed. Roughly 500 to 1,000 tons of cotton seed are certified annually.

Growers have made good use of the classing service provided by the Smith-Doxey Act to learn what their cotton is worth. So long as it

was available, they also took advantage of the opportunities afforded by the Federal Marketing Demonstration to demonstrate to the trade the improvement in Missouri cotton and to remove the prejudice which Missouri staple formerly met in the market.

Many interests and individuals cooperated wholeheartedly in advancing the improvement program. Growers, ginners, vocational agriculture teachers, and the University of Missouri, including particularly the county agents, marketing and crops specialists, and the experiment station naturally were closest to the over-all program. The Federal Ginning Laboratory and the Agricultural Marketing Administration have assisted very materially. The A.A.A. program has influenced the yield, particularly in stimulating the location of cotton on the better land and the application of practices that increase productivity of the soil. Cotton breeders made superior varieties available. The ground work and early plans for this development were laid by Dr. Ide P. Trotter of the Texas A. & M. College, and

TABLE 2.—*The development of the Missouri cotton improvement program.*

	1936	1937	1938	1939	1940	1941	1942 (preliminary)
Number Communities with 75% or More of Acreage Planted with Approved Seed							
	2	14	38	35	44	62	80
Percentage of Entire Crop Planted with Approved Seed							
	35*	55*	78	77	87	83	87
Yield of Lint per Acre, Lbs.†							
	360	346	450	555	454	549	522
Percentage of Crop 1 Inch and Longer							
Mo. av.	31.0	27.8	76.8	65.2	76.9	94.8	98.6
U. S. av.	43.0	33.6	51.9	49.3	59.5	62.5	63.6
Percentage of Crop Middling or Better in Grade							
Mo. av.	36.7	41.8	43.3	51.9	45.7	43.9	63.0
U. S. av.	72.6	52.8	76.9	66.7	61.2	49.9	59.2
Number of Gins Equipped with Driers							
	23	45	62	96	128	155	155

*Probable.
†392 lbs. per acre record yield through 1936.

TABLE 3.—*Number of organized one-variety improvement groups operating under Smith-Doxey Program.*

Year	Number of groups	Number of growers	Acreage	Percentage of state crop
1938	1	30	2,402	0.2
1939	9	320	14,689	3.9
1940	15	1,150	49,943	12.6
1941	55	5,018	185,045	44.5
1942	58	5,133	197,004	47.0

others, while serving as Extension Agronomist in Missouri preceding the writer.

The extent of improvement resulting from the combined efforts of groups cooperating in the program are shown in Tables 2 and 3.

In conclusion, it may not be amiss to say that those who have been most closely connected with the Missouri cotton improvement program feel that whatever measure of success it has attained is due principally to four facts, as follows: (1) The program was timely; (2) means of improvement were reduced to their simplest terms, thus avoiding confusing detail; (3) production and marketing of the crop were considered and treated as inseparably related; and (4) everyone concerned cooperated wholeheartedly.

While it is recognized, of course, that doubling the Missouri cotton grower's income is not due entirely to this program, it did put him in the position with the best crop he ever produced to make the most of the rise in price.

SECOND GENERATION PROGENY TESTS OF THE METHOD OF REPRODUCTION IN KENTUCKY BLUEGRASS, *POA PRATENSIS* L.[1]

W. M. MYERS[2]

SINCE the discovery by Müntzing (4)[3] of apomictic biotypes in *Poa pratensis*, there have been reported the results of several investigations of this problem, using the progeny test as a measure of the method of reproduction, including recent papers by Tinney and Aamodt (7), Åkerberg (2), and Brittingham (3). In determining the likeness of progeny and parent, the investigator has had to deal largely with quantitative characters which are greatly influenced by environmental as well as by heritable variations. Thus, there arise regularly borderline cases in which it is impossible to determine with certainty whether a progeny plant is or is not truly a parental type. Such difficulties in classification reduce the accuracy of measurement of the relative frequency of apomictic and sexual seed set. The variations resulting from environmental factors are particularly troublesome where single-spaced plants are used. This difficulty may be overcome partially by clonal increases or by progeny tests of each first generation plant. Progeny tests have the advantage over clonal increases of providing a measure of the method of reproduction of the first generation plant as well as providing a better basis for evaluation of morphological similarity or variance with the parental type.

Second generation progeny tests have two further advantages, *viz.*, data are provided regarding the genetical basis of apomictic versus sexual reproduction, and from the standpoint of breeding one can determine whether it will be profitable to continue selection of variant plants in progenies of sexual or partially apomictic plants with the hope of obtaining a highly apomictic biotype.

MATERIALS AND METHODS

From the plant progenies studied by Brittingham (3), three were selected as representative of the range from nearly apomictic to highly sexual seed production. These three progenies, namely, 37–172 (14), 37–38 (12), and 37–175 (46) were classified by Brittingham as having 3, 27, and 48% of variant type plants, respectively. From these progenies, 7, 23, and 26 plants, respectively, were selected from among those obtained from open-pollinated seed. In the first progeny, all selected plants were parental types, while in each of the latter two progenies there were selected six plants classified as parental types and the remainder classified as variant types. From each selected first generation plant and from each original parent, 60 plants from open-pollinated seed were transplanted

[1]Contribution No. 42, of the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture, State College, Pa., in cooperation with the northeastern states.

[2]Geneticist. The writer wishes to express his appreciation to Doctor Wm. H. Brittingham for supplying seed and clonal material of the parents and first generation plants used in this study.

[3]Figures in parenthesis refer to "Literature Cited", p. 418.

to the field. In rows adjacent to their respective seed progenies, five plants of the clone of each parental and first generation plant were set out. All data were collected during the second year of growth at the time when seed on the earliest plants was ripe.

For purposes of classification, dependence was placed insofar as possible upon characters which seemed to be affected by environmental fluctuations only to a limited extent. The characters studied included panicle type, size of floret, spikelet, and panicle, diameter of peduncle and panicle branches, relative length and width of leaf, large differences in height of flowering culms, earliness of maturity, color of the foliage, anthocyanin pigmentation particularly in the panicles, and resistance to various diseases. Each progeny plant was compared with the clonal row of its immediate parent and with sib plants which were thought to be similar to the parental type and then the plant was classed as variant type or parental type, i.e., like its immediate parent.

EXPERIMENTAL RESULTS

In the first generation progeny from 37–172 (14), which was classified as nearly apomictic, all 60 plants were classified as parental types. This is not significantly different from the 3% of variant types obtained by Brittingham. The clonal rows of six of the first generation plants appeared identical morphologically with the original parent. Among their progenies there were from 0 to 3.4% of off-type plants (Table 1). Therefore, also in breeding behavior, these first generation plants probably may be considered identical with the original parent.

The seventh first generation plant appeared upon superficial examination to be like the original parent, but more careful study revealed that it was slightly smaller with finer texture throughout, including smaller florets, spikelets, and panicles and narrower leaves. In the progeny of this plant there were 16.7% of variant types, indicating that the plant also differed from its parent in proportion of sexually to apomictically produced seeds.

Of the 60 plants in the first generation of the intermediate parent, 37–38 (12), 26.7% of the plants were classified as off-type. This is nearly identical with the value obtained by Brittingham (3) for breeding behavior of this plant. Eleven of the first generation clones seemed to be morphologically indistinguishable from the original parental clone. Among the progenies of five of these there were from 25.5 to 30.0% of variant types. It seems probable that these five clones were like their parent with regard to method of reproduction. Another of the parental type first generation clones had 20.0% of off-type progeny plants. This may possibly have been a chance deviation from parental type of breeding behavior. In the progenies of the remaining five parental type clones, there were 12.1, 15.0, 15.3, 17.0, and 17.0% of variant types. It seems probable that these five clones differed significantly from their parent in production of apomictic seeds.

The 12 variant-type first generation plants differed greatly in method of reproduction (Table 1). One had only 15.0% of off-type plants in its progeny, less than the original parent. A majority had more variable progenies than the parent, the extreme having 88.0% of

TABLE 1.—*Numbers of progenies showing indicated percentages of variant-type plants in the first generation and in the second generation from parental type and from variant-type first generation plants in 1942.*

Progeny and generation	Percentage of variant-type plants										
	0–5	6–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100
37-KB172(14) First......	1	—	—	—	—	—	—	—	—	—	—
Second Parental*	6	—	—	—	—	—	—	—	—	—	—
variant†	—	—	1	—	—	—	—	—	—	—	—
37–38 (12) First......	—	—	—	1	—	—	—	—	—	—	—
Second Parental	—	—	6	5	—	—	—	—	—	—	—
variant	—	—	1	1	2	3	1	2	1	1	—
37–175 (46) First......	—	—	—	—	—	—	1	—	—	—	—
Second Parental	—	—	—	—	—	—	—	—	1	2	—
variant	1	—	1	1	—	—	—	2	1	11	6

*First generation parent classified as like original parent on the basis of behavior in 1942.
†First generation parent classified as different from original parent on basis of behavior in 1942.

variant types. Some of the progenies were extremely difficult to classify and it is probable that some plants which were classed as parental types actually deviated somewhat from the parent morphologically. Therefore, the percentages of variant types recorded are probably low for the more variable progenies.

Of the six first generation plants of this family which were selected originally as parental types, five were included among the 11 clones classified morphologically as parental types in these investigations. One clone differed slightly but distinctly. Four of the five were among those which differed in breeding behavior from the original parent. Thus, only one of the six may be considered to have been produced from an apomictic seed. Here is evidence of the lack of reliability of first generation tests using single-spaced plants for measuring the amount of sexual seed production.

In the first generation progeny of 37–175 (46), there was recorded 59.3% of off-types, compared with 48% found by Brittingham (3). This progeny was very difficult to classify. The plants varied from those that were distinctly different from the parent to those that seemed similar to the parent but may have been only very slightly different. In the author's opinion, 59.3% was a conservative estimate

of the proportion of plants from sexual seeds. This conclusion was borne out by the results of the second generation tests.

Of the six plants selected as parental types, only three proved to be so when studied in clonal rows. These three plants had 70.9, 81.5, and 81.5% of variants among their progenies. All are significantly more variable than the first generation family, but because of the difficulties encountered in this family the differences may have been due partly to errors in classification of the individual plants. On the other hand, it is possible that these plants were truly different in breeding behavior. If so, the results would suggest that sexual reproduction was the rule in the original parent.

Progenies were classified from 23 variant-type first generation plants. Of these, 20 were more variable than the first generation and 18 were equal to or more variable than the progenies of the three parental types of first generation plants. Two progenies had 96.4 and 98.3% that were clearly variant types, while the classification of those plants recorded as parental types in these two progenies was questionable. These two first generation plants probably were very nearly or completely sexual in seed production.

In striking contrast to these plants, three had more uniform progenies than the original parent. One of the three had only 3.3% of variant-type plants in its progeny. Thus, a nearly apomictic plant was obtained among the progeny of a highly sexual type.

DISCUSSION

In the present investigation, the similarity or variance of progeny and parent has been accepted as a criterion of the type of embyro formation that has occurred. It is known that this test is not entirely accurate. According to the embryological studies of Tinney (6) and Åkerberg (1), the embryo sac develops usually by apospory in apomictic biotypes of *Poa pratensis*. In such biotypes, variant-type plants could arise by any one of three processes, *viz.*, (a) the parthenogenetic development of a reduced egg which was the product of meiosis, (b) the development of the embryo from a fertilized reduced egg, or (c) development of the embryo from a fertilized aposporous egg. The former type could be classed as apomictic, the latter two types as sexual. Brittingham (3) reported that by far the greatest number of aberrant types in his material had arisen by fertilization of a reduced egg cell by a reduced male gamete, while the parthenogenetic development of a reduced egg cell occurred rarely. Thus, it appears that a very large proportion of the variant type plants may be considered to have been developed by a sexual process. The classification of progeny plants as apomictically or sexually produced dependent upon their similarity or variance with the parental type seems, therefore, to be justified in the investigations reported in this paper.

The results obtained in these investigations emphasize the lack of reliability of first generation progeny tests for estimating accurately the proportion of apomictic seeds produced by a plant. When the investigator is dependent upon single-spaced plants, it is impossible

to distinguish accurately between slight variations caused by soil heterogeneity or other environmental factors and those attributable to heritable differences. Recognizing the role of environment in conditioning morphological differences among plants, the investigator usually will be inclined towards the conservative course and classify many such doubtful cases as parental types. Thus, the estimated frequency of apomictic seeds will be higher than that actually obtained. Another factor contributing to this error is that even among progenies of sexual plants there frequently are some offspring that bear a striking resemblance to the mother plant. This raises the question of how many of the so-called parental types were actually produced by sexual processes but differ only slightly from the maternal parent.

Replication by clonal increases to the extent used in this experiment evidently does not supply a satisfactory answer to these problems. Thus, in the case of the progeny of 37–38 (11), at least five of the plants which were classified by clonal rows as parental types were found from tests of breeding behavior to be variant types. In studies of method of reproduction by progeny uniformity trials, it appears that advanced generation tests are necessary to obtain entirely reliable information.

Despite their unreliability, first generation progeny tests are useful for picking out large differences. Thus, the results of these investigations were in general agreement with Brittingham's (3) conclusions regarding breeding behavior of the three original parental plants. In the type of Kentucky bluegrass breeding program outlined by Tinney and Aamodt (7), it would not be possible to conduct second generation progeny tests of all selected plants. It is probable that first generation tests will serve for elimination of the highly sexual types prior to plot testing as Tinney and Aamodt (7) proposed. However, the results of the present investigations suggest that second generation progeny tests should be conducted with strains that have proved superior in plot trial before seed of these strains are released. In fact, such tests could be used as the basis for the first seed increase of superior strains.

The results obtained here lend support to Brittingham's (3) conclusions regarding the incidence of sexual types in Kentucky bluegrass. He found a higher frequency of sexual seed production than had been reported by most previous workers. There was the possibility that Brittingham had erred by classifying as variant types some plants that were different due only to environmental fluctuations. However, the second generation progeny tests of his material indicated that such errors were at least not the rule. Actually, Brittingham's (3) estimation of the frequency of sexual types was low in the three families used in the experiments reported here.

Müntzing (5) and Åkerberg (1, 2) have reported that variant types exhibit more highly sexual behavior than their parents. Müntzing interpreted these results as indicating that apomixis is determined by a balanced "constellation of genes" and that any disturbance of this balance results in a lesser degree of apomixis. The results reported in this paper agree in general with those obtained by Müntzing and

Åkerberg. The aberrant type plants had, in most instances, higher percentages of off-type plants among their progenies than the parental types had. However, some striking exceptions were found. One individual among the progeny of the highly sexual plant [37–176 (45)] was nearly apomictic as judged by the uniformity of its progeny. The occurrence of occasional variant plants with increased apomictic seed set may be accounted for by the hypothesis of genetical control of apomixis. The first generation plants used in this study were obtained from open-pollinated seed produced by the mother plants when growing in the nursery with plants which varied from nearly completely apomictic to highly sexual. Since pollen from apomictic plants was present, it is not surprising to find occasionally a plant from a sexually produced seed that has the proper gene combination to make it capable of apomictic reproduction. The results indicate that it is possible to find apomictic plants among the open-pollinated progenies of partially or highly sexual plants. However, the frequency of such plants seems from these results to be too low to make an extensive search for them profitable except in special instances.

SUMMARY

1. Second generation progeny tests were made of plants from three first generation progenies of Kentucky bluegrass which had been found in previous investigations by Brittingham (3) to contain 3, 27, and 48% of variant-type plants.

2. The results were in general agreement with those of the first generation tests. However, errors in classification were found as was expected, particularly in that some plants which had been classified as parental types were proved by their progenies to be variant types.

3. In general, variant-type plants produced a higher proportion of sexual seeds than did their parents or parental type sibs. However, occasional variant-type plants were found to be more nearly apomictic in breeding behavior.

4. It was concluded that first generation progeny tests do not provide an accurate measure of the relative frequency of sexual and apomictic seed production. Such tests are sufficient, however, for indicating large differences and for preliminary evaluation of the method of reproduction of selected plants in a breeding program.

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FIELD PERFORMANCE OF BROMEGRASS STRAINS FROM DIFFERENT REGIONAL SEED SOURCES[1]

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FOR many years commercial grass seed has been purchased with the belief that "grass is grass" and similar performance has been expected from all seed. The demands for grass plantings in the adjustment of crop acreages, in soil conservation programs, and in the rejuvenation of drought-depleted pastures in general has led to the wide distribution of seed. The importance of seed quality has been stressed, but differences in the adaptation of strains have not been fully realized. Accordingly, farmers in certain areas have frequently met with distinct success or outright failure, depending on the choice of seed for planting. Such results are more likely to occur toward the periphery of the region of adaptation of a particular grass. This is the case with bromegrass, *Bromus inermis* Leyss., a cool-season grass, when its region is extended southward.

Many acres of bromegrass have been planted in Nebraska since the drought years of 1934 and 1936. Old fields previously pastured have been allowed to produce seed and much seed has been shipped into the state to supply this new demand. Enthusiastic claims concerning successful plantings have been made by many farmers. On the other hand, some have reported failure in securing suitable stands, while others who have reported good stands have been dissatisfied with the production obtained. This situation led to the planting in 1939 of a field test to determine the behavior of strains of bromegrass obtained from different seed sources.

HISTORICAL

Distinct differences in plant type had been noted in bromegrass nurseries at Lincoln, Neb., between plants originating from northern sources and plants from old fields in Nebraska and northern Kansas. The results later obtained from plot tests indicate that wide differences exist between strains in their adaptation to this region. To account in part for these variations, it is of interest to examine the history of bromegrass in reaching commercial importance in this country.

Bromegrass was introduced into the United States from continental Europe. Although some seed may have been brought in by immigrants, the earliest re-

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corded importation was made by the California Agricultural Experiment Station through France from Hungary. This seed was distributed to a number of states, including Kansas and California, in 1884 (1).[3] Some of this seed was no doubt grown at the South Dakota Station during the five years preceding 1895 at which time it was being recommended (5). During this early period, the grass was known as Hungarian bromegrass.

Experiment stations and farmers in Kansas, Montana, Texas, Colorado, Nebraska, North Dakota, Washington, Oregon, and other states cooperated in testing seed distributed during the years 1896 to 1899 by the U. S. Dept. of Agriculture Division of Agrostology (2). Kansas and Nebraska each received one of the earliest consignments of this seed in 1896–97. Although its original source has not been definitely traced, it is probable that the bromegrass seeded in 1897 and 1898 at the Nebraska Experiment Station, on which a report was made in 1899, was from this consignment (3). Most of the farmer cooperators received their seed during the period 1897 to 1899. According to Kennedy (2), "The larger part of this seed was purchased from Russia".

Beginning in 1898, several shipments of seed were made to the South Dakota Experiment Station from Russia. These were undoubtedly from latitudes more comparable to Canada than to Nebraska and Kansas. During the years following, the grass came to be known in many regions as Russian bromegrass. Since the seed shipments were large, it is likely that they became distributed widely in the Dakotas and Canada where seed production has reached commercial importance to the extent of export to other states.

During the last few years, some of the original plantings in Nebraska have been discovered by tracing the origin of more recently seeded fields. Two original fields have been found which date to plantings made in 1897 and 1898. The source of seed for these plantings was probably the same as that of the Experiment Station seedings of those dates. Experiment Station records show numerous exchanges of seed between farmers and the Experiment Station at that time and during the years immediately following. Fields which became established as a result of these trials furnished seed for other fields in the same locality. This spread has been slow until the last few years, but several generations of plants have undoubtedly been produced. There have been numerous exchanges of seed between farmers in southern Nebraska and northern Kansas. The oldest fields in Nebraska and Kansas and the fields derived from them have given responses in tests similar to the type here referred to as the southern type of bromegrass. During the past few years the seed production from these fields has become sufficiently large to meet much of the local demand.

MATERIAL AND METHODS

The strains of bromegrass for this test were chosen from old fields or known centers of seed production to represent the range of adaptation of the species from north to south in the Great Plains. Regional strains ranged in origin from Canada to Kansas. These strains with what is known of their history are listed in Table 1. The 24 strains are grouped into northern or southern types as determined by origin and performance. Two Canadian selections, Parkland and Superior, were included in the test. Six commercial lots, obtained through seed firms, were secured by them from individual farms without blending of the seed. Three old fields from northeast Nebraska had a known history which placed these strains

[3]Figures in parenthesis refer to "Literature Cited", p. 434.

in the northern group. The remaining Nebraska strains proved to be of the southern type. These southern strains are undoubtedly related, although their history in many cases cannot be definitely traced. Strain 4 was derived from strain 24 which was known to have been secured from a Kansas field in 1916 by Mr. Bert Mott of Hastings, Nebr. Similarly, the Kansas fields are probably all related to the well-known strain grown by Achenbach Brothers of Washington, Kan. According to correspondence, this strain was obtained from a farm near Sutton, Nebr. This illustrates the exchange of seed which has taken place in this region. Several generations of plants are known to have been grown on individual farms.

The test of these strains was conducted on the Agronomy Experimental Farm at Lincoln, Nebr., and was laid out on upland soil considered representative of farm conditions under which bromegrass was being seeded in Nebraska. The land used had been farmed for over 40 years and had been more recently used for tests of soil fertility, comparing the effects of manurial treatments with and without lime and phosphorus. These treatments in 1/10-acre plots had been applied between 1921 and 1936 after which the ground had been uniformly cropped. Each replication of bromegrass strains was laid out with the plots of all strains lying across the previous treatments. This afforded a means of testing the strains over a variety of soil fertility levels. In addition, an application of nitrogen fertilizer was made on half the replications in 1942, using a double-disk type of fertilizer drill which placed the fertilizer in the surface inch of soil. Although the recommendations for seeding bromegrass usually include a legume, the seedings were made in pure stand in order to test strain differences more easily.

The seeding was made September 8, 1939. Three blocks of two replications each for measuring forage production of the 24 strains were planted in 60-foot plots consisting of seven drilled rows 10 inches apart. Two blocks each with two replications were planted in 25-foot plots of seven rows for measuring seed production and observing other agronomic characters. Forage and seed production were obtained from the center five rows. The strains were randomized with the restriction that two strains would not fall side by side or end to end more than once in either of the tests. Forage yields were obtained with a push-type power mower, cutting at approximately 2½ inches from the ground level. Seed was harvested by hand and uniformly cleaned.

RESULTS AND DISCUSSION

Observations during the fall of 1939 and the subsequent growing season indicated that one of the difficulties of stand establishment of commercial bromegrass in Nebraska may be the use of unadapted seed. Although excellent initial stands as to number of plants were obtained, the plots differed greatly in appearance during the period of their establishment. Both the source and the seed quality of the strain appeared to be factors affecting the seedling vigor exhibited (Fig. 1). In spite of excellence of seed quality, most of the northern strains produced very weak seedlings during the short days of fall and early spring. The two Canadian selections, Parkland and Superior, were the least vigorous in the seedling stage. The commercial seed from northern sources produced better plants than the selections, although there was much variation between strains as shown by the observations made on April 19, 1940, and recorded in Table 1. Where excellence of seed quality was found in locally adapted strains from old fields in Nebraska and Kansas, a remarkable seedling vigor was obtained. (Fig. 1 and Table 1).

During the months of May, June, and July, 1940, rainfall was below normal and during the latter part of this period the seedlings were subjected to a period of hot dry weather. Much drying and browning of the leaves occurred. Observations on July 18, 1940, indicated that the degree of this response was directly associated with the sources of the strains (Table 1). The southern strains appeared to be more tolerant to midsummer heat and drought than the northern strains. None of the plots made sufficient growth to warrant harvest in 1940.

In the spring of 1941, striking differences were exhibited by the

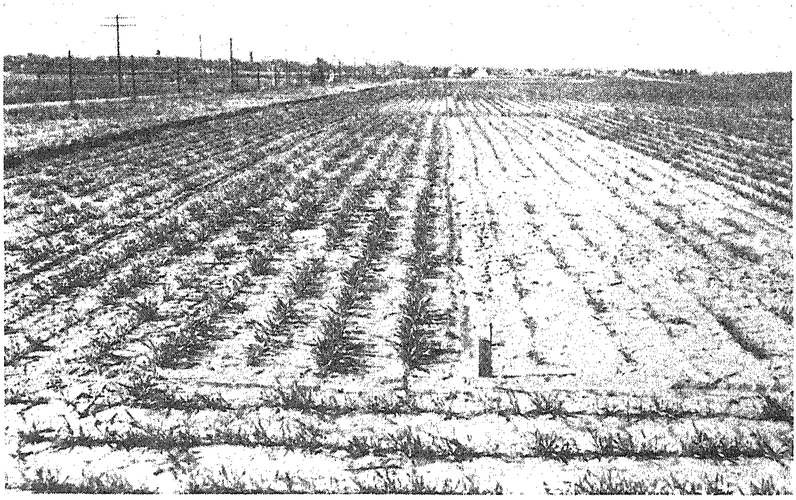

FIG. 1.—Extremes of seedling vigor exhibited by bromegrass strains from different sources. On the right, a strain of northern origin; on the left, a locally adapted strain from an old field in southern Nebraska. Photographed May 2, 1940.

strains from different sources, the southern strains making the most growth. Toward the middle of May moisture became a limiting factor. By May 18, the southern strains had reached maximum panicle production. Fewer panicles had been formed on the northern strains at that date, indicating a tendency for lateness. Pollination on all strains occurred on May 30 and was completed on both types of strains during the several days following. The plots for forage were mowed on June 5 (Fig. 2). Seed was harvested from the balance of the plots during the early part of July. Both forage and seed production are given in Table 1.

The groups of strains gave increasingly larger forage production from sources from north to south. Standard errors for measuring the significance of differences were computed from a generalized error obtained by an analysis of variance, the value of n being determined by the number of plots involved. The North Dakota group of strains gave average yields significantly higher than the Canadian group.

TABLE 1.—*First-year performance and second-year forage and seed production of bromegrass strains from different regional seed sources.*

Strain No.	History of strain				Seedling vigor, Apr. 19, 1940*	Drought and heat tolerance, July 18, 1940*	Yield per acre in 1941	
	Source or name	Original planting, year	Location	Original source			Forage (12% moisture), tons†	Seed,‡ lbs.
				NORTHERN STRAINS Canada				
3	Parkland	—	Saskatoon	Selection	8.8	8.4	0.91	215
17	Superior	—	Saskatoon	Selection	8.8	8.2	1.04	227
11	Commercial	—	Winnipeg	—	5.8	7.7	1.02	164
14	Commercial	—	Calgary	—	6.2	7.9	1.16	128
20	Commercial	—	N. W. Manitoba	—	3.8	7.7	0.99	149
Av....	—	—	—	—	6.7	8.0	1.02±08	155±29
				North Dakota				
7	Commercial	—	Bismark (No. 1)	—	4.0	6.5	1.24	176
16	Commercial	—	Bismark (No. 2)	—	3.7	6.4	1.53	240
23	Commercial	—	Ryder	—	6.6	7.3	1.21	249
Av....	—	—	—	—	4.8	6.7	133.±.10	187±38
				Nebraska				
1	Walt Fenske	1931	Hoskins	Northern in 1902	6.1	6.5	1.46	392
5	H. H. Pfeiffer	1919	Arlington	Wisconsin	4.4	6.7	1.54	180
22	T. B. Bowman	1903	Albion	Germany	5.7	6.0	1.59	181
Av....	—	—	—	—	5.4	6.4	1.53±.10	231±38
Av. of northern strains.............					5.8	7.2	1.24±.05	184±20

				SOUTHERN STRAINS				
				Nebraska				
2	Joseph Hruska	1924	Schuyler	Local seed Co.	4.7	4.0	2.35	199
4	H. Lauber	1938	Geneva	J. B. Saltzman	5.2	5.6	1.90	394
8	H. Bartlett	1936	Beatrice	Local seed Co.	4.5	4.2	2.20	219
9	C. W. Cook	1936	Arlington	Roadsides	5.1	4.7	2.26	393
12	Wes Fry	1937	Virginia	Experiment Station	6.1	5.7	2.49	489
15	Jacob Wiebe	1936	Beatrice	Local seed Co.	5.5	4.0	2.15	293
18	R. J. Egger	1931	Martel	Local seed Co.	2.4	4.2	2.31	374
19	J. F. Halderman	1936	Pawnee City	Local seed Co.	4.4	5.4	2.22	490
24	J. B. Saltzman	1924	Shickley	Bert Mott, Hastings	3.1	4.4	2.42	382
Av....	—	—	—	—	4.6	4.7	2.26±.06	322±22
				Kansas				
6	Achenbach Bros.	Prior to 1898	Washington	Sutton, Nebr.	3.7	3.9	2.21	183
10	Walter Zenger	1924	Haddam	Achenbach Bros.	4.0	3.8	2.46	272
13	Griffee Bros.	1929	Marysville	Achenbach Bros.	4.8	4.6	2.03	263
21	Frank Weber	1925	Morrowville	Local	3.4	3.2	2.29	282
Av....	—	—	—	—	4.0	3.9	2.25±.09	245±33
Av. of southern strains					4.4	4.4	2.25±.05	298±18

*Average of ratings of ten plots: 1–2, Excellent; 3–4, Good; 5, Medium; 6–7, Fair; 8–9, Poor. Plot ratings varied from 2 to 9.
†Average of six replications. A minimum difference of 0.50 ton between yields of any two strains is required for significance at the 5% level.
‡Average of four replications. A minimum difference of 183 pounds between yields of any two strains is required for significance at the 5% level.

Average yields of the North Dakota and Nebraska groups of northern strains do not differ significantly and the average yields of the two groups of southern strains are nearly the same. However, the average yield, $1.53 \pm .10$ tons, of the Nebraska northern strains is significantly different from the yield of the Canadian group, $1.02 \pm .08$, and from the yields of both groups of southern strains, $2.26 \pm .06$ and $2.25 \pm .09$ tons, respectively. The difference of $1.01 \pm .07$ tons between the average yields of northern and southern strains is highly significant.

A small amount of re-growth occurred on the northern strains following this cutting. Due to summer drought and heat, this re-growth soon dried and was found to be too small in quantity to be harvested. The southern strains, however, had reached their maximum produc-

FIG. 2.—Differences in growth habit and production between strains of bromegrass. On the left, one of the best plots of a commercial northern strain as compared to a southern strain on the right. Photographed June 4, 1941.

tion and were dormant during the summer months. The small amount of fall growth was not harvested but was left on the plots for winter protection.

Seed yields in 1941 showed a trend similar to those of forage yields (Table 1). The southern strains produced the larger yields, ranging as high as 490 pounds per acre. Due to a high variability between all strains and between plots within the replications, no significance can be ascribed to differences between adjacent groups of strains in the table within the northern or within the southern types. The difference of 114 pounds between the average yields of northern and southern strains is highly significant.

In 1942, the strains were tested under two levels of fertility secured by applying 250 pounds of ammonium sulfate per acre to one half of the replications on April 2. The replications to which the treatment was applied were chosen on the basis of the 1941 yields. In the forage production test the replications were divided into two sets of three replications each, one from each of the three blocks. Each set included replications with relatively high and relatively low average

yields of plots. The two sets of replications gave somewhat comparable yields. In the seed production study the two sets of replications were similarly chosen, one from each of the two blocks. The set of replications in each study which had given the lower average yield of the two sets was selected for fertilization.

Forage yields were secured by clipping twice in May in order to measure the production of the strains on a basis more comparable to pasturing conditions. Moisture was not a limiting factor in the 1942 spring production. There was a rainfall of 2.82 inches during March. However, it appears probable that the ammonium sulfate application might have been more effective if applied earlier since in April rain did not occur until the 16th and 25th in sufficient amounts to incorporate the fertilizer into the top soil. A rainfall of 5.47 inches in May was above normal.

Total forage and seed yields of the strains are given in Table 2. Forage yields in 1942 were much lower than in 1941 since the plots had apparently passed a peak in forage production. It appears that the southern strains had also passed a peak in seed production, since they gave rather low seed yields and were surpassed by the northern strains. The Canadian strains produced the least forage in both years. However, they gave a higher seed yield in 1942 than in 1941 and produced the highest seed yield of all of the strains in 1942. Strain 16 from Bismark, N. Dak., gave forage yields in both years comparable to strains from northern Nebraska, while the other two Dakota strains were more nearly like those from Canadian sources. Strain 1 was outstanding in seed production in the Nebraska group of northern strains for both years. Strain 2 of the southern group was especially vigorous with relatively high forage but low seed production in its group for both years. This strain is known to have undergone considerable natural selection since 1924 on a very fertile soil. The Nebraska and Kansas strains exhibited a remarkable similarity of forage yields by groups, especially in 1942. The seed yields, however, were highly variable, a few strains maintaining a relatively high seed production in both years. The significance of differences in forage and seed yields between groups of strains from different sources is presented and discussed in connection with Tables 3 and 6, showing the effects of the fertilizer treatment.

The averages of groups of strains are used in Table 3 to show the effects of the fertilizer application on forage yields. With each group of strains the three replications which received ammonium sulfate produced average yields significantly larger than those of the untreated replications. The trend of yields by latitude groups was similar to that obtained in 1941. The "t" values in the last column of the table indicate which differences between adjacent groups are statistically significant. Reference to tables (4) for the value of "t" with 92 degrees of freedom (for error) show that for a comparison of any two groups, minimum values of 1.99 and 2.63 would indicate significance at the 5 and 1% levels, respectively. There are significant differences in average yields, at the 5% level or greater, between all groups of strains except between the Nebraska and Kansas groups of southern type. These gave nearly the same average forage yields. The differ-

TABLE 2.—*Third-year forage and seed production of bromegrass strains from different regional seed sources.*

Strain No.	Source or name	Yield per acre in 1942	
		Forage (12% moisture) tons	Seed, lbs.†
	NORTHERN STRAINS		
	Canada		
3	Parkland	0.82	232
17	Superior	0.71	227
11	Commercial	0.75	148
14	Commercial	0.87	116
20	Commercial	0.84	166
Av.	—	0.80±.04	178±12
	North Dakota		
7	Commercial	0.97	116
16	Commercial	1.11	176
23	Commercial	0.93	186
Av.	—	1.00±.05	159±16
	Nebraska		
1	Fenske	1.18	224
5	Pfeiffer	1.10	144
22	Bowman	1.11	163
Av.	—	1.13±.05	177±16
Av. of northern strains	—	0.94±.02	173±8
	SOUTHERN STRAINS		
	Nebraska		
2	Hruska	1.36	80
4	Lauber	1.23	172
8	Bartlett	1.20	98
9	Cook	1.26	119
12	Fry	1.29	96
15	Wiebe	1.24	97
18	Egger	1.29	125
19	Halderman	1.28	185
24	Saltzman	1.29	185
Av.	—	1.27±.03	129±9
	Kansas		
6	Achenbach	1.33	63
10	Zenger	1.37	76
13	Griffee	1.22	96
21	Weber	1.29	111
Av.	—	1.30±.04	87±14
Av. of southern strains	—	1.28±.02	116±8

*Average of six replications. A minimum difference of 0.22 ton between yields of any two strains is required for significance at the 5% level.

†Average of four replications. A minimum difference of 79 pounds between yields of any two strains is required for significance at the 5% level.

TABLE 3.—*Average total forage fields per acre of bromegrass strains from untreated and fertilized plots harvested twice during May, 1942.*

Source	Number of strains	Untreated, three replications, tons	Fertilized, three replications, tons	Average, six replications, tons	Difference	t value
			Northern Strains			
Canada......	5	0.68	0.92	0.80	—	—
					0.20	3.51
North Dakota	3	0.84	1.17	1.00	—	—
					0.13	2.03
Nebraska.....	3	1.02	1.24	1.13	—	—
Av........	11	0.81	1.08	0.94	—	—
			Southern Strains			
					0.14	2.69
Nebraska....	9	1.13	1.41	1.27	—	—
					0.03	0.64
Kansas......	4	1.19	1.41	1.30	—	—
Av........	13	1.15	1.41	1.28	—	—
Between average yields of northern and southern strains					0.34	10.62

ence, 0.34±.03 ton, between the average yields of northern and southern strains is highly significant.

An analysis of variance shows a highly significant value of F for strains and for treatment (Table 4). There was no significant interaction between strains and treatment which indicates a similar response of all the strains to the fertilizer application. The effect of the ammonium sulfate was apparently less important than the action of other environmental factors, such as day length, temperature, etc., in determining the strain differences. This indicates that similar

TABLE 4.—*Analysis of variance of the 1942 bromegrass forage yields.*

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Total........................	143	15.8730	—	—
Strains......................	23	5.7541	0.2502	6.87**
Blocks.......................	2	2.9845	1.4923	41.00**
Treatment..................	1	2.4623	2.4623	67.65**
Strains × treatment...........	23	1.0505	0.0457	1.26
Blocks × treatment............	2	0.2713	0.1357	3.73*
Remainder or error............	92	3.3503	0.0364	—

*Significant at the 5% level.
**Significant at the 1% level.

differences between strains would have been found had the test been conducted on a more fertile soil. This assumption has been confirmed by later tests on fertile bottomland soil at Lincoln, Nebr., using other farmer-produced strains and seed from commercial sources in addition to a few of the strains of this test as standards.

A presentation of the data as obtained on the two clipping dates reveals a fundamental difference between the strains from different latitude sources (Table 5). The first clipping, May 8, gave the more striking differences between groups of strains with the southern strains yielding over twice as much as the average of the northern strains. However, the northern strains produced a larger yield than the southern strains in the second clipping. These figures suggest the designations of "late" and "early" strains, respectively, for the northern and southern groups of strains. This relation is more easily seen when the yields of each group are considered from the standpoint of the percentage of their total growth produced at each clipping. From north to south the groups produced an increasingly larger percentage of their total growth in the first clipping. The average figures show that the northern strains produced 37% of their growth in the first clipping as compared to the southern strains which produced 63% by this date. Had there been a period of dry weather in May, it is likely that much of the production of the late strains would have been curtailed as it was in 1941. Because of drought hazards, early strains are accordingly desired for the region served by this test.

TABLE 5.—*Average forage yields per acre of bromegrass strains obtained on each of two dates of clipping in May, 1942.*

Source	Number of strains	First clipping May 8		Second clipping May 28		Total, tons
		Tons	% of total	Tons	% of total	
		Northern (Late) Strains				
Canada	5	0.24	30	0.56	70	0.80
North Dakota	3	0.37	37	0.63	63	1.00
Nebraska	3	0.51	45	0.62	55	1.13
Av.	11	0.35	37	0.59	63	0.94
		Southern (Early) Strains				
Nebraska	9	0.80	63	0.47	37	1.27
Kansas	4	0.83	64	0.47	36	1.30
Av.	13	0.81	63	0.47	37	1.28

There were marked differences in appearance of forage produced by the replicated plots on different levels of fertility. The replications receiving the ammonium sulfate treatment produced forage with a dark green color in contrast to untreated replications. This was apparent in late April and throughout May. Samples for measuring the

crude protein content (nitrogen$\times$6.25) were taken just prior to the two dates of harvesting the forage plots. On May 1, the 24 strains were sampled on each of four different fertility levels. On a low-yielding, sodbound replication the average protein content of all strains was 16.6%. The average protein content of strains from three sets of samples taken from unfertilized replications was 19.3%. A replication which had given the lowest yields in 1941 and which had received the ammonium sulfate application in 1942 produced forage at the first clipping with an average protein content of 25.8%. There were no significant differences in protein content of the strains by groups at this date of sampling.

The fertilized replication which was sampled for protein proved to be the highest yielding replication in 1942. Another set of samples taken on May 27 from this fertilized replication gave an average protein content of 23.6% for the forage harvested in the second clipping. These samples, of course, represented different proportions of total growth produced by the strains because of their different rates of growth (Table 5). At this level of fertility the northern strains averaged 2.7% higher in protein than the southern strains. On the same date, additional samples were taken from paired plots of northern and southern strains throughout the field from different replications. As an average of 11 paired plots, the protein content of the northern strains was 18.9 while that of the southern strains was 15.8%. This difference of 3.1% between northern and southern strains appears to be evidence of differences in maturity between the strains at this date. Since the southern strains were the more vigorous and productive, the forage from these strains contained the larger total of protein in the two clippings. Their more extensive use of nitrogen explains the difference in the intensity of green color frequently noted between northern and southern strains when nitrogen becomes limiting.

The effect of fertilization on seed production is presented in Table 6. The average yield of the two fertilized replications was larger for all of the groups of strains than the average yield of the untreated replications. The northern strains were the most productive. With fertilization, the groups of strains gave yields which decreased in amount in order according to source from north to south. The significance of differences between the group yields obtained as an average of four replications is shown in the last column of Table 6. The differences in yield between adjacent groups of northern type are small and insignificant. The differences between the two groups of Nebraska strains and between the Nebraska and Kansas groups of southern type appear significant. The difference of 57 pounds in average yield between strains of northern and southern type is highly significant.

An analysis of variance of these data again shows a highly significant value of F for strains and for treatment (Table 7). As a grand average of all of the strain yields, the increase of 83 pounds of seed (Table 6) due to the ammonium sulfate is highly significant. With a favorable ratio between the cost of fertilizer and the price of seed, a profit could be shown for the use of a nitrogen fertilizer in bromegrass seed production.

TABLE 6.—*Average seed yields per acre of bromegrass strains from untreated and fertilized plots harvested in 1942.*

Source	Number of strains	Untreated, two replications, lbs.	Fertilized, two replications, lbs.	Average, four replications, lbs.	Difference	t value
			Northern Strains			
Canada......	5	120	236	178		
					19	0.95
North Dakota	3	115	203	159		
					18	0.78
Nebraska.....	3	154	201	177		
Av........	11	128	217	173	—	—
			Southern Strains			
					48	2.67
Nebraska....	9	89	168	129		
					42	2.47
Kansas.......	4	49	125	87		
Av........	13	77	155	116	—	—
Grand av...	24	100	183	142	—	—
Between average yields of northern and southern strains					57	5.18

TABLE 7.—*Analysis of variance of the 1942 bromegrass seed yields.*

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Total........................	95	718,789	—	—
Strains........................	23	226,555	9,850	3.18**
Blocks........................	1	5,325	5,325	1.72
Treatment...................	1	165,917	165,917	53.61**
Strains × treatment...........	23	43,078	1,873	0.61
Blocks × treatment...........	1	135,526	135,526	43.79**
Remainder or error............	46	142,388	3,095	—

**Significant at the 1% level.

Tests of additional bromegrass strains planted at Lincoln, Nebr., subsequent to the 1939 seeding have substantiated the data here presented. In all, over 60 strains obtained directly from farmers' fields or otherwise carefully checked as to origin have been observed in these tests. Of particular interest has been the lack of seedling vigor of the strains of northern type during the short days of fall and spring. This is especially noticeable with strains of northern type when planted in August or September for fall establishment, a customary practice in the region. Such differences in seedling vigor have

not been as noticeable with spring planting, if cool weather prevails into early summer and moisture is not limiting. However, spring-planted tests show the same striking differences in yielding ability of northern and southern strains when measured in subsequent years as do fall-planted tests.

The outer limits of the region in which these strain differences may be expected to occur have not been fully determined. Preliminary tests indicate that the differences become less pronounced when the strains are grown farther north or at higher altitudes. This probably accounts for the fact that strains of both northern and southern type are being grown successfully in northeast Nebraska. No very old fields of distinctly northern type have been found in southern Nebraska, either because of failure to become established or because they have proved unsatisfactory as to production and have been plowed.

The distinct differences in the appearance and production of the northern and southern strains shown in these tests suggest that the two types of strains have been derived from different parent material. What is known of the history of the original seed introductions appears to offer a probable explanation. At Lincoln, Nebr., tests of bromegrass seed more recently introduced from Europe tend to substantiate the conclusion that the two types are associated with the latitude of the source. Two strains (F.P.I. Nos. 111,273 and 111,274) obtained from the Cluj Botanic Gardens, Cluj, Roumania, in 1935, are similar in appearance and production to the locally adapted strains of southern Nebraska. Several introductions (F.P.I. Nos. 115,329 and 115,331 to 115,335, inclusive) secured from Leningrad, U.S.S.R., in 1936, produced such small plants lacking in vigor that the strains were not maintained. Strain 22 in these tests, reported to have been introduced to this region directly from northern Germany many years ago, appears to be intermediate to these two introductions. Its general appearance and production indicate that it is a strain of the northern type. Several generations of natural selection have undoubtedly occurred with this strain in northern Nebraska, making it outstanding in these tests over strains from farther north. The variability in individual plants, as well as the field performance of both the northern and southern strains, indicates that since their introduction these strains have been further modified by local environment.

SUMMARY

Striking differences in the success of bromegrass plantings on farms in Nebraska suggested a test of strains from different seed sources. Strains were obtained from old fields and known centers of seed production to represent the region of adaptation of the grass from north to south in the Great Plains. A field test including 24 strains from Canada, North Dakota, Nebraska, and Kansas was planted in September, 1939. The strains were observed and data obtained during three seasons. In all, a total of 60 such strains were observed in this and subsequently planted tests.

On the basis of their origin and performance, the strains tested

were placed into two general groups here referred to as northern and southern types.

The strains of southern type produced more vigorous seedlings under short days of fall and early spring, were more tolerant of drought and heat, possessed more vegetative vigor, and were more productive under the conditions of this test than the strains of the northern type.

The highest yields of forage of all strains were obtained in the second year after seeding, the yields by groups of strains increasing in order according to source of strains from north to south. The southern strains also gave their highest seed yields in the second year, outyielding the northern strains. The northern strains maintained relatively high seed yields in the third as compared to the second year of production, and accordingly gave somewhat larger seed yields than the southern strains in the third year.

Southern strains produced a larger percentage of their total forage in early spring than the northern strains. Under the conditions of this study, the designations "early" and "late" are thus suggested for the strains of southern and northern type, respectively. The southern or early strains are preferred in the region served by these tests, since the relatively low production of late-producing strains may be further curtailed by recurrent spring and summer droughts.

The effects of nitrogen fertilization on the forage and seed productions of the strains were measured. Both forage and seed yields, as well as the protein content of the forage, were increased by the fertilizer application. Other factors in the environment were apparently more important than the level of nitrogen availability in determining the relative yields of the strains, as all strains responded similarly to fertilization.

The results of this study show that variations in bromegrass, similar to the variations in other cross-pollinated crops, occur from farm to farm as well as between regions. These variations appear to have resulted from the selective effects of environmental factors operating both before and after the introduction of this grass into the United States.

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MORPHOLOGICAL CAUSES FOR VARIETAL DIFFERENCES IN SHATTERING OF WHEAT[1]

S. C. CHANG[2]

WHEAT breeders in China have noted that one of the most undesirable characters of Chinese varieties of wheat is their extreme susceptibility to shattering of the kernels. This is in contrast to the introduced varieties, most of which are highly resistant to shattering. Shattering of kernels may occur before harvest while the crops are still standing in the field or during the harvesting operations. Since harvesting on Chinese farms is done by hand labor with a sickle and since transportation to the farm yard is also by hand, the losses may be great. Therefore, resistance to shattering of the kernels is an important character.

This study was undertaken to measure varietal differences in certain American wheats and to determine if any relationship exists between these differences and various agronomic and anatomical characters.

LITERATURE REVIEW

Recently, Vogel (6, 7)[3] reported a direct relationship between relative resistance to shattering and the extent of mechanical tissue at the breaking point of the glumes. When using a mechanical measure of "glume strength", he found a relationship between glume strength and shattering in certain varieties but not in others. He concluded that a greater glume strength is required to produce a given degree of resistance to shattering in certain combinations of head characters than in others.

Dunkle (3) tested the resistance of wheat varieties to shattering by means of a specially constructed machine. He stated that he was able to determine small differences between varieties. Of 13 head and grain characters only 3 were significantly correlated with shattering. Awn length and number of grain per head were found to be negatively correlated and width of grain positively correlated with resistance to shattering.

In inheritance studies of shattering of wheat kernels, Clark, *et al.* (2) found that the extent of shattering in F_2 progenies of three crosses increased with the length of the awns even though the awned parent was the most resistant and the awnless parent the most susceptible.

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[1]From a thesis submitted to the University of Minnesota in partial fulfillment of the requirements for the degree of Doctor of Philosophy. This paper represents but one phase of the thesis. Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 2059 of the Sci. Journal Series, Minnesota Agricultural Experiment Station. Received for publication January 16, 1943.

[2]Agronomist, Division of Wheat and Miscellaneous Crops, National Agricultural Research Bureau, Ministry of Agriculture, Chungking, China. The writer wishes to express his sincere appreciation to Dr. H. K. Wilson, Dr. R. B. Harvey, and Dr. H. K. Hayes for their valuable suggestions and criticisms during the course of this study; and to Dr. E. C. Abbe and Dr. F. K. Butters for helpful suggestions in the anatomical phases of the investigations. He also wishes to acknowledge the aid of Dr. C. R. Burnham who has checked the main conclusions from the slides in the anatomical study and who has checked the final form of this manuscript for publication.

[3]Figures in parenthesis refer to "Literature Cited", p. 441.

Lewicki (4) believed that the relative resistance of a wheat variety to shattering of kernels varies with the relative degree of separation of the glumes, including lemma and palea, i.e., strength of insertion of wheat kernels in the glumes. In his inheritance studies "weak insertion" was found to be dominant in F_1 in crosses of both awned and awnless wheats. A single factor was involved in most cases, although in one case three factors seemed to be involved. While weak insertion and awns did not appear to be linked in inheritance, F_2 plants with bearded spikes shattered to a much greater extent than awnless spikes.

MATERIAL AND METHODS

On the basis of the information obtained by personal correspondence with certain wheat investigators in the United States, six varieties of spring wheat representing varying degrees of resistance to shattering were selected for the present studies. These were Garnet, Rival, Ceres, Marquis, Mindum, and Hope. In addition to these, the spring wheat varieties in the 1/40 acre plots of 1939 and 1940, at University Farm, St. Paul, Minn., were included.

A machine was constructed (Fig. 1) for testing varietal differences in resistance to shattering. For its operation one man holds the wheat heads while the other rotates the crank (Fig. 1,B), causing the rubber paddle (Fig. 1,I) to strike the wheat

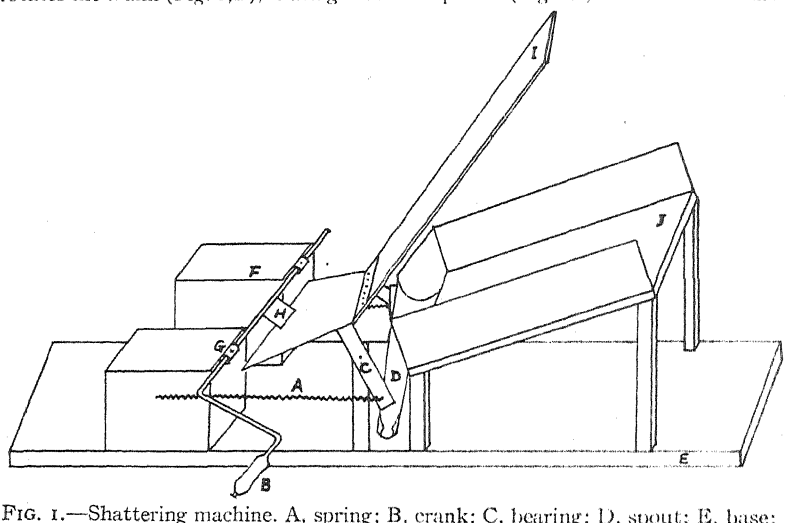

FIG. 1.—Shattering machine. A, spring; B, crank; C, bearing; D, spout; E, base; F, bearing blocks; G, bearings; H, cam; I, paddle; J, shattering board.

heads. The heads were held in the same position on the shattering board (Fig. 1,J) and the crank was rotated at a speed of 70 revolutions per minute. To make each stroke as uniform as possible, a spring (Fig 1,A) was attached to the bearing (Fig. 1,C) and the crank was operated by the same person. At maturity 100 typical spikes were harvested from each of three plots. Three heads were tested in each trial and 20 trials were made from each plot. The percentage of shattering for each plot was determined by averaging the records of the 20 trials. Wheat heads were tested 50 days after harvesting in 1939 and 10 days after harvesting in 1940.

For a study of the attachment of the wheat kernels and its relationship to shattering, five varieties, Garnet, Rival, Thatcher, Mindum, and Hope, representing varying degrees of resistance to shattering, were selected. Material of

each of these varieties was collected at six stages of growth, corresponding roughly to blooming, milk, early, medium, and late dough, and maturity. The central and the secondary flowers of each spikelet were removed and the primary flower together with its attached portion, but with glume and lemma removed, were killed in Randolph's Craf Solution (5). An air pump was used to remove the free air.

After fixation for 24 to 36 hours, the flowers were softened in 25% hydrofluoric acid. The three younger stages were treated for 7 days and the three more mature stages were treated for 10 days. Material was imbedded in rubber-beeswax-paraffin, but the more mature stages cut better when imbedded in "Tissuemat".

For a study of the anatomical structures of the glume, lemma, and palea in relation to shattering resistance, the same five varieties were selected, together with Mercury, Premier, Regent, Vesta, and Brandon 123. Four central spikelets from each of several typical heads of the 10 varieties were collected at maturity from plants grown in the greenhouse and in the field. Only the lower side flower of each spikelet was used. The glume and the lemma and palea, together with the attached portion of the rachis, were fixed in 70% alcohol. After fixing, they were treated with 25% hydrofluoric acid for 7 days.

Longitudinal sections of the glumes were cut perpendicularly to the broad side of the glume and those of the lemma and palea were cut from the narrow side. Cross sections of the upper two thirds of the matured glume and lemma were made separately. All sections were cut at a thickness of 12.5 microns.

To study the relationship of certain head and grain characters to shattering, 30 typical heads were selected from each of the varieties and the following characters were determined: length of awn, length of lemma, width of grain, number of grains per head, weight per 1,000 kernels, and average length of rachis internode. For measuring the length of awn, length of lemma, and width of grain, the two side flowers of each of the four central spikelets of each head were used, i.e., eight measurements for each of these characters on each head.

EXPERIMENTAL RESULTS

VARIETAL DIFFERENCES IN RESISTANCE TO SHATTERING

The varieties of wheat tested for shattering in 1939 and 1940 are listed in Table 1, together with the percentages of shattering as determined by means of the shattering machine illustrated in Fig. 1. The estimated variances of the separate varieties are not homogeneous, since the susceptible varieties showed a greater variation than the more resistant ones. When a transformation of these percentages to $\sin^2\theta$, as suggested by Bliss (1), was made, the calculated Chi-square value of the 1940 results showed homogeneity. Analysis of variance could thus be made of the transformed results of both the 1939 and 1940 experiments. The standard error of a difference was 1.650 in the 1939 experiment and 1.259 in the 1940 experiment. Significant varietal differences were shown in both years. There was no significant interaction between years and varieties in this study and the varietal rank was similar in both years' results. By using three times the standard error of the difference for the average of the two years' results (3.375), the varieties could be arranged into seven groups, ranging from the most susceptible to the most resistant as follows: (a) Mercury, Garnet; (b) Premier, Rival; (c) Pilot; (d) Ceres,

Merit, Mindum; (e) Thatcher, Nordhougen, Coronation, Marquis, Renown; (f) Regent, Marquillo; (g) Vesta, Brandon 123, Hope.

TABLE 1.—*Shattering percentages of spring wheat varieties at University Farm, St. Paul, Minn., in 1939 and 1940.*

Variety	1939	1940	Average
Mercury*	31.89	27.39	29.64
Garnet*	29.43	26.98	26.20
Premier*	23.09	22.28	22.68
Rival*	20.29	21.87	21.08
Pilot	14.05	12.32	13.18
Ceres	9.58	10.83	10.20
Merit	9.73	9.45	9.59
Mindum*	10.21	8.96	9.58
Thatcher*	9.51	6.52	8.01
Nordhougen	7.94	7.77	7.85
Coronation	7.56	6.62	7.09
Marquis	8.34	5.72	7.03
Renown	6.74	5.37	6.05
Regent*	5.56	3.86	4.71
Marquillo	2.84	3.74	3.29
Vesta*	2.31	2.54	2.42
Brandon 123*	2.14	1.92	2.03
Hope*	1.20	1.42	1.31
Standard error of a difference	1.65	1.26	1.13

*Varieties used in the anatomical study of the empty glume.

RELATIONSHIP BETWEEN A GROUP OF MORPHOLOGICAL CHARACTERS AND SUSCEPTIBILITY TO SHATTERING

Eighteen varieties of spring wheat grown in 1/40 acre plots at University Farm, St. Paul, Minn., were used. The correlation coefficients between amount of shattering and the various head and grain characters were .52 for length of lemma, .42 for width of grain, .42 for average length of rachis internode, .40 for weight per 1,000 kernels, .13 for number of grains per head, and .03 for length of awn, of which only that with length of lemma was significant, although width of grain, average length of rachis internode, and weight per 1,000 kernels gave correlation coefficients only a little below the 5% level of significance. The effect of all characters together, except length of awn, on resistance to shattering was measured by determining the multiple correlation coefficient. A coefficient of .62 was obtained, indicating that about 38% of the total squared variability in shattering of the 18 varieties might be attributed to its relation to these five characters.

The results indicate that the shorter the lemma and possibly the narrower the grain, the shorter the rachis internode, and the smaller the weight of kernel a variety possesses, the greater the chances that this variety will have a lower percentage of shattering. This may mean that as the lemma and the rachis internode become shorter and the kernel becomes lighter and narrower less surface will be exposed to the striking board of the shattering instrument. The same may be

true in their exposure to external agencies which cause shattering of kernels under field conditions.

HISTOLOGY OF THE SEED ATTACHMENT

The longitudinal and cross sections of the basal portion of the ovary with its attached portion of the rachis for Garnet, Rival, Mindum, Thatcher, and Hope at six stages of development from blooming stage to maturity showed no positive indication of a relationship between anatomical structure and resistance to shattering of kernels.

ANATOMICAL STRUCTURE OF EMPTY GLUME, LEMMA AND PALEA

Longitudinal sections of the first or empty glumes of the starred varieties listed in Table 1 were studied, comparisons being made of sections at the central, peripheral, and intermediate regions. In all the most resistant varieties, represented by Hope in Fig. 2, there was

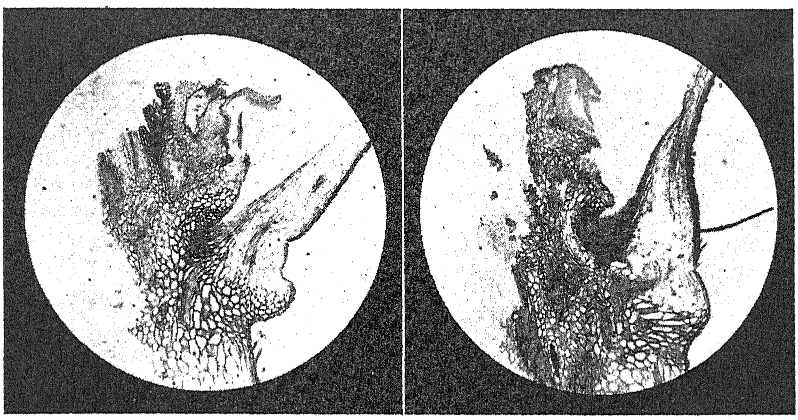

FIG. 2.—Longitudinal sections of the basal portion of the empty glume (X75) taken at a point midway between the central region and the periphery of the glume. Hope (right), a variety resistant to shattering, shows a greater amount of thick-walled tissue in the axil than does Garnet (left), a susceptible variety.

much more thick-walled tissue in the inner basal portion than in the most susceptible varieties, represented by Garnet in Fig. 2. In the moderately resistant varieties, such as Regent and Thatcher, there was more thick-walled tissue than in the most susceptible varieties, but less than in the most resistant ones. It was not possible to measure accurately the relative amounts of such tissue to determine if the smaller differences in shattering resistance could be related to small differences in amounts of thick-walled tissue.

With the exception of Mindum, the greatest amount of thick-walled tissue was located in the peripheral and the least in the central region, although in all three regions in the most resistant varieties there was

more thick-walled tissue than in the most susceptible ones.[4] In Mindum, the only *durum* variety included, the least thick-walled tissue was located in the peripheral region. This may be an anatomical difference between *durum* and *vulgare* varieties.

Cross sections were made of the upper portion of the empty glume in Hope, Vesta, Regent, Thatcher, and Garnet. The tissue was largely sclerenchymatous in all the varieties, but the cell walls of Regent were much thicker than any of the other varieties. Next in order of decreasing wall thickness was Vesta, then Thatcher, followed by Hope and Garnet. These latter two varieties showed very little difference in cell wall thickness, but the walls were thinner than those of any of the other three varieties. Hope and Vesta were equally resistant to shattering, yet Hope in the upper portion of the outer glumes was similar in cell structure to Garnet, one of the most susceptible varieties. It is evident that the structure of this portion of the glume plays a less important role in shattering resistance than does the structure of the basal portion. Regent was more resistant to shattering than Thatcher. This difference may have been due to the added strength of the thicker walled cells in the upper portion of the empty glume, since both had about the same amount of thick-walled tissue in the inner basal portion of the empty glume.

Longitudinal sections of the lemma in Garnet, Mercury, Rival, Mindum, Thatcher, Vesta, and Hope showed anatomical differences in the inner basal portion similar to, but to a much smaller degree than, those observed in the empty glume. These differences were observed only in the outer peripheral regions. In all other portions of the lemma no varietal differences were observed.

The paleae failed to show any great amounts of lignified tissue, nor could any varietal differences be determined.

SUMMARY AND CONCLUSIONS

1. Differences in amounts of shattering of 18 varieties of spring wheat were measured by means of a specially constructed machine. The amounts varied from 1.3% in Hope to 29.6% in Mercury.

2. No anatomical differences in seed attachment could be observed.

3. A direct relationship was observed between the amount of strengthening tissue in the inner basal portion of the outer glume and resistance to shattering.

4. A similar relationship was also observed for the inner basal portion of the lemma, but there was less thick-walled tissue and it was located only in the peripheral regions. No such relationship was observed in the paleae.

[4]Examination of Dr. Chang's sections at the time this manuscript was being prepared for publication suggests that the thickness and shape of the basal portion of the outer glume may be important in certain cases. In longitudinal sections in both resistant varieties, Vesta and Hope, the base was much thicker and more pyramid-shaped than in Garnet. (Fig. 2). In Regent, however, with moderate resistance, the base was not thicker than in Garnet. Since sections of the glumes of all the varieties were not then available for examination, this suggestion is made only in the hope that those studying this problem may be interested in checking the point.—C. R. BURNHAM.

5. Cross sections of the upper portion of the empty glume showed the tissues to be largely sclerenchymatous with differences in cell wall thickness in certain varieties. Except possibly in combination with an intermediate amount of strengthening tissue in the inner basal portion of the empty glume, greater cell wall thickness in the upper portion seems to play a minor role in resistance to shattering.

6. The thickness and shape of the base of the outer glume may affect resistance to shattering in certain varieties but the evidence is incomplete.

7. Of a group of six grain and head characters of 18 wheat varieties, length of lemma, width of grain, average length of rachis internode, weight per 1,000 kernels, number of grains per head, and length of awn, only the correlation coefficient between length of lemma and susceptibility to shattering was above the 5% level of significance. The multiple correlation coefficient between the first five characters and shattering percentage was .62, indicating that these do as a group contribute to differences in shattering.

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THE EFFECT OF MATURITY ON THE VIABILITY AND LONGEVITY OF THE SEEDS OF WESTERN RANGE AND PASTURE GRASSES[1]

DEAN F. MCALISTER[2]

IN recent years there has been a considerable demand for grass seeds of both native and introduced species for reseeding in the West. The variation in types of seeds, in seeding habits of the species needed, and the lack of experience in handling the seeds of many of the species has resulted in various problems, not only to those interested in commercial seed production, but also to those engaged in grass research. One of these problems is the amount of shattering before or during the harvesting process which depends on the species, weather conditions, and harvesting methods. The possibility suggested itself that perhaps losses due to shattering might be avoided by harvesting before the seeds were fully ripe.

This study was made to determine the earliest stage in development at which seeds of *Agropyron cristatum* (L.) Gaertn., crested wheatgrass; *A. smithii* Rydb., western wheatgrass; *A. trachycaulum* (Link) Malte, slender wheatgrass; *Bromus inermis* Leyss, smooth brome; *B. marginatus* Nees., mountain brome; *B. polyanthus* Scribn.; *Elymus glaucus* Buckl., blue wildrye; and *Stipa viridula* Trin., green needlegrass, could be harvested without loss in viability, longevity, and vigor of the seedlings following germination. Shattering had previously been observed in all of these species with the exception of *B. inermis*.

Most of the investigations dealing with seed maturity in the grass family have been carried out on the small grains and corn. Lehmann and Aichele (6)[3] have reviewed most of these studies, as well as those dealing with forage grasses. In general, it has been found that the seeds of members of the Gramineae will germinate and produce seedlings when harvested as early as the milk stage of development. Harlan and Pope (2) found that five out of seven barley varieties produced viable seeds as early as 6 days following pollination. In a study on the time of cutting as related to the production of viable seeds, Gill (1) found that *Hordeum nodosum* and *Bromus mollis* produced viable seeds when cut in the milk-ripe condition. Hermann and Hermann (3) conclude from germination and emergence tests of seeds of *Agropyron cristatum* collected at 10 stages of maturity, from pre-milk to fully mature, that "vigorous plants probably cannot be expected from seed harvested earlier than in the hard dough stage." They found, however, that good germination could be obtained from seeds harvested in the early dough stage.

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[1]Contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, in coöperation with the Utah Agricultural Experiment Station, Logan, Utah. Received for publication January 20, 1943.

[2]Assistant Physiologist.

[3]Figures in parenthesis refer to "Literature Cited", p. 452.

MATERIALS AND METHODS

Seeds of 1-year-old plants of *Agropyron cristatum*, *A. smithii*, *A. trachycaulum*, *Bromus inermis*, *B. marginatus*, *B. polyanthus*, *Elymus glaucus*, and *Stipa viridula* were collected in different stages of maturity in 1937. With the exception of the Fairway strain of *A. cristatum*, the species were represented by spaced plants grown under irrigation from seeds of native or commercial sources. The seeds were harvested while in the following stages of development: Pre-milk, milk, dough, and maturity. The endosperm of seeds taken in the pre-milk stage had reached its full length but was thin, green, nearly transparent, and upon crushing a clear greenish sap exuded. At the milk stage of development the seeds were becoming well filled and the endosperm was pale green in color, yielding a milky fluid upon crushing. Seeds collected in the dough stage were apparently fully developed so far as size was concerned, the endosperm generally an amber green, the contents doughy in texture, and the glumes, hitherto entirely green, showed some drying or browning at the tips and margins. When the mature seeds were collected, the glumes were brown or straw color, the endosperm hard, and the culm below the inflorescence had lost its green color.

In *Agropyron trachycaulum*, *Bromus inermis*, *B. marginatus*, *B. polyanthus*, and *Stipa virdula*, it was found that the seeds at the tips of the inflorescences matured earlier than those at the base. For this reason, seed was collected only from the central portions of such panicles or spikes. Even on the same spikelet the basal floret bloomed as much as 2 or 3 days before the apical floret. Thus, since single seeds were not collected, there was some variation in the maturity of seeds in any one sample.

The dates of full bloom for these species in 1937 were from June 25 to 29, except for *Agropyron smithii* which was in full bloom July 10. Pre-milk samples were collected 13 to 16 days after full bloom and subsequent samples at intervals of 4 to 6 days.

Seed samples, consisting of 10 spikes, or panicles, were taken from 10 to 20 individual plants of each species. Samples of *Bromus marginatus*, *B. polyanthus*, and *Stipa viridula* were bulked at the time of collection, while the individual samples from each plant of *Agropyron cristatum*, *A. smithii*, *A. trachycaulum*, *Bromus inermis*, and *Elymus glaucus* were kept separate. The spikes and panicles were spread out and allowed to air-dry in the laboratory immediately after collection. After threshing and cleaning the seeds were placed in paper packets and stored in a laboratory storeroom at 15° to 23° C. The moisture content of the seeds was 7 to 9% during storage.

Soil tests were used to determine the viability of the seed samples. The tests were run in the greenhouse, using a sandy loam soil in which the seeds were planted at a depth of ¼ inch. During the germination periods the soil temperature was 22° to 25° C. In the first three tests of viability, duplicate 25-seed lots were used of the individual plant samples and duplicate lots of 50 seeds each were taken for the bulk collections. In subsequent tests, following bulking of the single plant samples of a like degree of maturity, four lots of 50 seeds each were tested for each stage of maturity of each species. Final germination counts were recorded 14 to 16 days after planting. A seed was considered germinated when it had produced a normal seedling.

RESULTS

RELATIVE WEIGHTS OF SEEDS

To obtain an accurate check on the size of the seeds collected at the different stages of maturity, the weights of hulled seeds were de-

termined for each sample. It was found that the weights of the hulls on immature seeds were about the same as on mature seeds and so a comparison of the weights of seeds enclosed in hulls did not present a true picture of the development. In Table 1 the weights of 100-seed samples of mature seeds with and without hulls and the relative weights of immature hulled seeds are given.

The data presented in Table 1 show considerable variation in the relative weights of the seeds harvested in the pre-milk stage of maturity. The extremes were 16 to 44 for *Elymus glaucus* and *Bromus inermis*, respectively, and an average of 31 for all species, compared with 100 for mature seeds. Much less variability was shown in the relative development of the seeds in the two other immature samples. The seeds of the milk stage were a little over one-half as heavy as mature seeds and those collected at the dough stage were about three-fourths as heavy.

TABLE 1.—*Relative weights of grass seeds collected at different stages of maturity.*

Species	Weight in grams of 100 mature seeds		Ratio of weights of mature vs. immature hulled seeds, mature seed = 100		
	Unhulled	Hulled	Dough	Milk	Pre-milk
A. cristatum	0.20	0.14	74	53	29
A. smithii	0.51	0.32	79	52	—
A. trachycaulum	0.32	0.23	72	54	31
B. inermis	0.37	0.28	84	64	44
B. marginatus	1.17	0.90	83	64	23
B. polyanthus	0.83	0.66	81	59	43
E. glaucus	0.44	0.30	77	52	16
S. viridula	0.40	0.28	76	—	34

With the exception of *Bromus inermis*, all species showed some shattering as, or before, the seeds reached maturity. In *B. marginatus*, *B. polyanthus*, and *Stipa viridula*, shattering was observed by the time the dough stage was reached.

GREENHOUSE SOIL GERMINATION TESTS

The soil germination tests showed striking differences in the rate of emergence of seedlings produced by seeds harvested at different stages of development. In appearance, the seedlings from dough stage seeds could not be distinguished from those from mature seeds. The sprouts from milk or pre-milk seeds, however, were noticeably smaller than those from more mature seeds. Seedlings from pre-milk seeds were distinctly less vigorous than those from milk stage seeds. The production of seedlings lacking a fully developed coleoptile or the development of an empty coleoptile was observed frequently in the sprouts from the two immature stages.

In the first three germination tests, no statistically significant differences were observed between plants in rate or total germination

of the seeds collected from individual plants of *Agropyron cristatum*, *A. smithii*, *A. trachycaulum*, *Bromus inermis*, and *Elymus glaucus*. Hence, for further testing, the seeds of like stages of maturity of each species were bulked.

The results of the germination tests conducted over a period of 58 months after harvesting the seed samples are presented graphically in Figs. 1, 2, and 3. The variance in these experiments was found to be fairly uniform. Differences between germination values of at least 13.1% were required at the 0.05 level of significance in the first three tests. For the last four storage periods, in which the number of seeds and replications of each sample were doubled, a difference of 9.4% was required for significance.

Wheatgrasses.—The upper set of curves in Fig. 1 shows the results of the germination tests with seeds of *Agropyron cristatum*. It is apparent that the dough and mature seeds had similar viability in all tests. In no instance was there a difference between the two types of seed greater than 8%. The milk stage seeds of this species gave lower germination than the more mature seeds, while the pre-milk seeds had a much lower viability than those harvested in the milk stage, especially after 15 months of storage. The milk, dough, and mature seeds showed little loss in viability in 58 months of storage. Initial values were 73, 90, and 95% compared with 79, 88, and 84% in the final test for the milk, dough, and mature seeds, respectively. The viability of the pre-milk seeds decreased from 77 to 36% in 22 months with no further loss during the remainder of the period of storage.

The seeds of *Agropyron smithii* gave maximum germination during the first 15 months of storage. The maxima were 86, 92, and 93% for the milk, dough, and mature seeds, respectively. Differences in viability of the dough and mature seeds were small over most of the period. Milk stage seeds generally gave lower percentage germination than dough and mature seeds, but the final test showed the seeds collected in the milk stage to be as high in viability as those harvested at maturity. After a decline following the 15-month test, the mature seeds maintained their viability above 80% until more than 4 years old. A sharp drop in viability occurred after the 51-month test in both the dough and mature seeds. Final germination values were 62, 53, and 63% for the milk, dough, and mature seeds, respectively.

The curves in the bottom section of Fig. 1 show the germination behavior of slender wheatgrass, *Agropyron trachycaulum*, seeds collected at different stages of maturity. Four months after collection, the germination was 73, 89, 90, and 98% for the pre-milk, milk, dough, and mature seeds, respectively. The mature seeds had a viability of over 90% for 40 months of storage and then dropped rapidly to 24% by the end of 58 months. The dough seeds showed a maximum germination at 22 months of 95% compared with a like maximum for milk-stage seeds at 15 months. A marked loss in viability was found in both stages after 22 months of storage, the milk-stage seeds decreasing more rapidly than those of the dough stage. The pre-milk seeds retained their viability of about 75% for 15 months and then dropped to 30% at 22 months with only a slight decrease during the rest of the storage period.

Bromegrasses.—The germination data obtained from seeds of the bromegrasses are presented in Fig. 2. The curves in the upper graph give the percentage germination of the seeds of *Bromus inermis* of different degrees of maturity. Mature seeds gave 95% or better

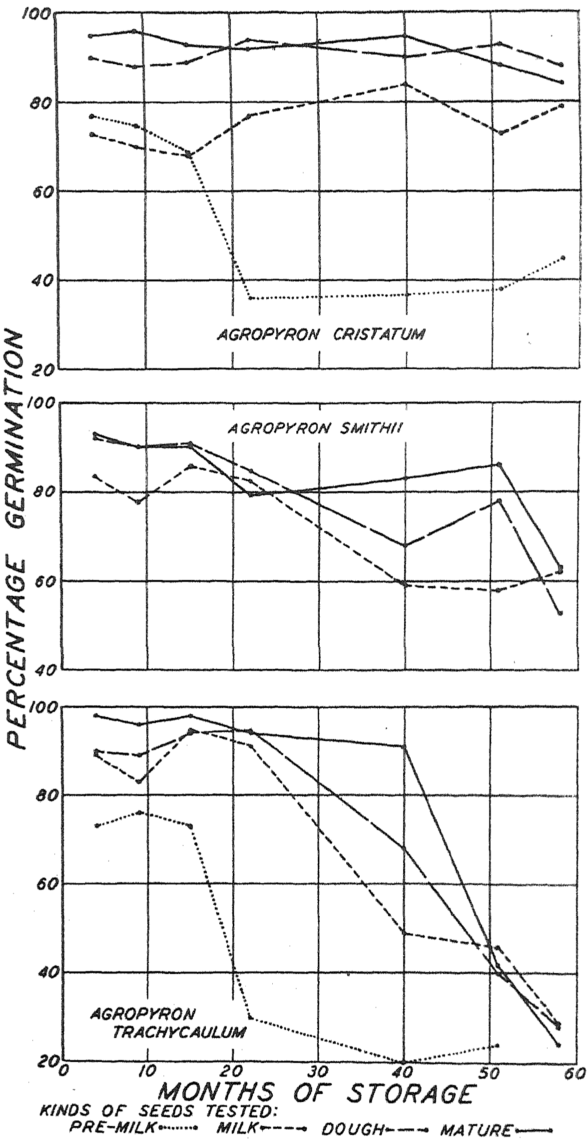

FIG. 1.—Percentage germination of seeds of *Agropyron cristatum*, *A. smithii*, and *A. trachycaulum* collected at pre-milk, milk, dough, and mature stages of development after 4, 9, 15, 22, 40, 51, and 58 months of storage.

germination during 22 months of storage, then gradually decreased in viability to 78% by the end of 58 months. The dough stage seeds decreased from 95% at 4 months to 76% at 58 months, while the milk seeds decreased in viability from 91 to 68% over the same period.

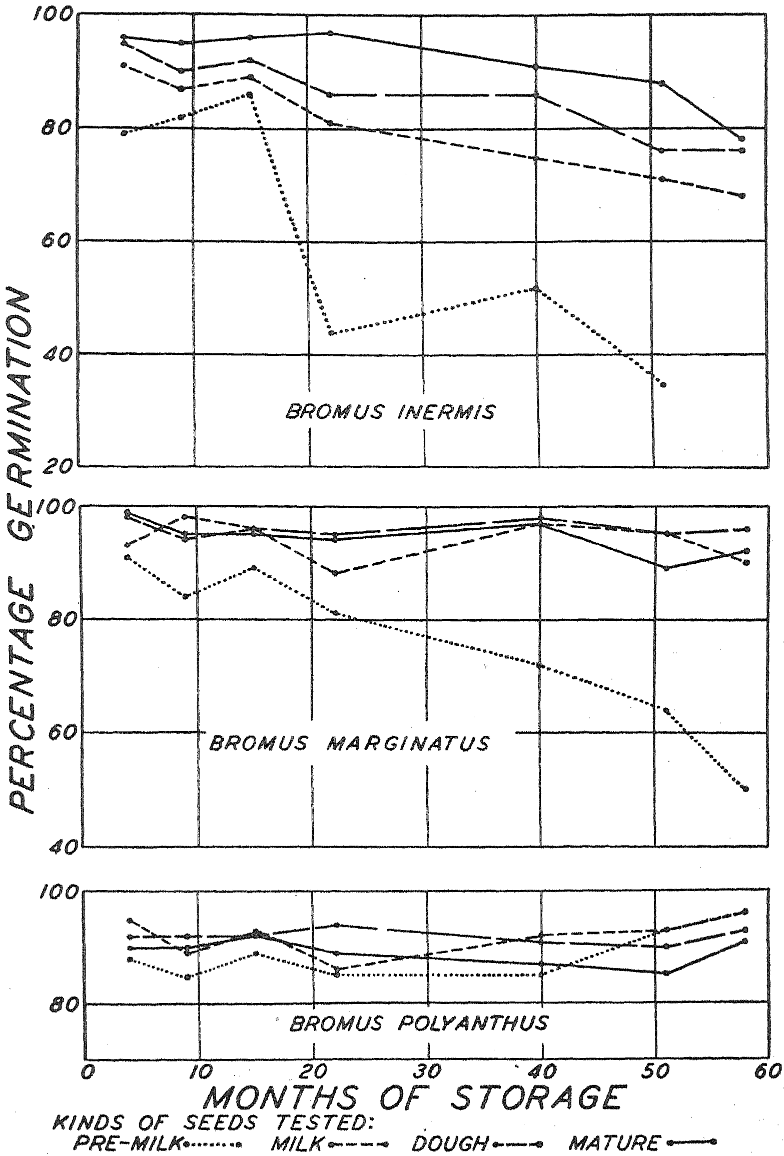

FIG. 2.—Percentage germination of seeds of *Bromus inermis*, *B. marginatus*, and *B. polyanthus* collected at pre-milk, milk, dough, and mature stages of development after 4, 9, 15, 22, 40, 51, and 58 months of storage.

Pre-milk seeds increased from 79% after 4 months of storage to 86% at 15 months and then lost viability rapidly until at 51 months a value of 35% was observed.

No significant differences were apparent between the germination values obtained for the milk, dough, and mature seeds of *Bromus marginatus* during the course of the experiment. Seeds of these stages germinated from 93 to 99% at 4 months and 90 to 96% after 58 months of storage. The pre-milk seeds were definitely inferior to those of the other degrees of maturity, decreasing from 91% viability at 4 months to 50% at the end of 58 months.

Reactions of the *Bromus polyanthus* seed samples to the germination tests are presented in the lower section of Fig. 2. The seeds of all stages of maturity were equally viable throughout the 58 months of storage. Four months after harvest the pre-milk, milk, dough, and mature seeds gave germination values of 91 to 98% and after 58 months, 91 to 96%.

Elymus glaucus and Stipa viridula.—In Fig. 3 the results of the germination of the seeds of *Elymus glaucus* and *Stipa viridula* are given. The mature seeds of *E. glaucus* maintained a high viability (above 92%) for 22 months, and then decreased rapidly to only 2% by the end of 58 months of storage. A closely similar behavior was observed with both dough and milk stage seed of the same species, except that the viability of the milk-stage seeds was noticeably lower throughout the tests. Following a rise in viability between the 9- and 15-month tests, the pre-milk seeds gave nearly the same germination as the milk seeds.

Germination data in the lower graph of Fig. 3 show a long after-ripening response in the seed samples of *Stipa viridula*. Mature seeds of this species had a viability of 28% at 4 months, 89% at 15 months, and then a gradually increasing viability until 98% germination was found after 51 and 58 months of storage. The dough stage seeds gave an initial germination of 20% at 4 months and no increase until the 22-month test. After 58 months of storage, these seeds gave a maximum germination of 93%. Pre-milk seeds of this species showed an increase of the same character as the dough seeds but with lower values, 5% at 4 months and 53% after 51 months of storage.

TABLE 2.—*Average percentage emergence of seedlings under field conditions from 9-month-old grass seeds harvested at different stages of maturity.*

Species	Stage of development			
	Maturity	Dough	Milk	Pre-milk
A. cristatum	46	33	10	3
A. smithii	35	29	16	—
A. trachycaulum	52	31	27	19
B. inermis	52	39	26	21
B. marginatus	52	47	46	18
B. polyanthus	56	57	56	30
E. glaucus	64	51	34	8
S. viridula	3	6	—	1

FIELD PLANTINGS

In addition to the greenhouse germination tests, field plantings were made with seed from the samples collected at different stages of maturity. Duplicate lots of 25 seeds each from these samples were

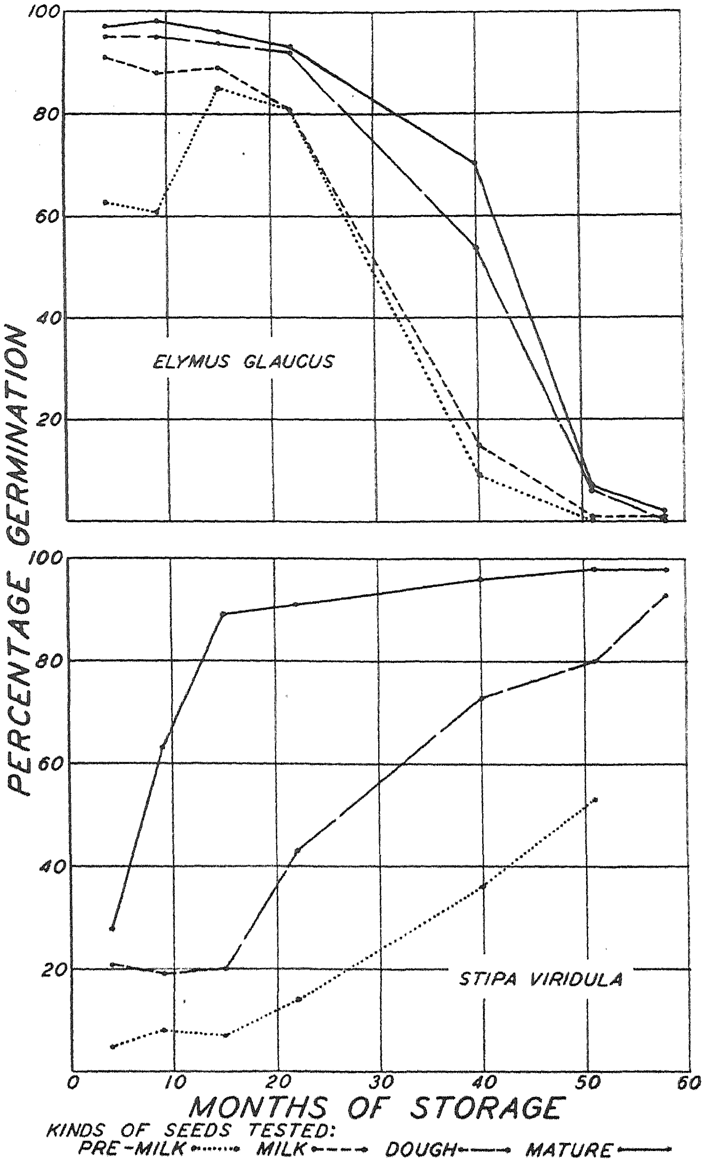

FIG. 3.—Percentage germination of seeds of *Elymus glaucus* and *Stipa viridula* collected at pre-milk, milk (*E. glaucus*), dough, and mature stages of development after 4, 9, 15, 22, 40, 51, and 58 months of storage.

planted in the field during April in each of the three years 1938, 1939, and 1940. These plantings were made to determine the relative vigor of the seedlings produced from seeds of varying degrees of maturity. Average emergence values for the 1938 planting are given in Table 2.

While the data in Table 2 are not considered quantitative due to the small numbers of seeds and seedlings involved, some general observations are possible. The mature seeds of all species, except *Agropyron smithii* and *Stipa viridula*,[4] gave a little more than half as many seedlings in the field planting as in the greenhouse test at 9 months. The dough stage seeds of *Bromus marginatus*, *B. polyanthus*, and *Elymus glaucus* gave values similar to those of mature seeds, compared with 39% emergence or less for the other species. Only in *B. marginatus* and *B. polyanthus* seeds harvested in the milk stage were the emergence values as high as for mature seeds. All other species fell below 35%. The pre-milk seeds produced relatively few seedlings in all species. In the 1939 and 1940 field plantings, only the *B. marginatus* seeds of the mature and dough stages gave as many seedlings as in the 1938 test. All other seeds, both mature and immature, showed evidences of loss in their ability to produce seedling under field conditions.

Since the plots on which the plantings were made were not irrigated, it was expected that any weak seedlings might be eliminated during dry periods of the summers. However, observations in late October in each of the years in which a planting was made showed no greater decrease in numbers of seedlings from immature than from mature seeds. When the survival notes were taken, there were no apparent differences in size between seedlings from mature and immature seeds.

DISCUSSION

Although these experiments were not conducted for a sufficient length of time to obtain the complete life span of mature seeds of these species, the greenhouse tests indicated that seeds of all but *Bromus marginatus*, *B. polyanthus*, and *Stipa viridula* had decreased in viability by the end of 58 months of storage. Of the remaining species, seeds of *Elymus glaucus* decreased in viability the most rapidly, dropping sharply after 2 years to nearly zero in the last test. The seeds of *Agropyron cristatum* decreased only slightly, *A. smithii* 30%, and *A. trachycaulum* two-thirds or more in their viability in 58 months. *Bromus inermis* seeds lost 18% in germination during the course of the greenhouse tests.

Lehmann and Aichele (6) have stated that grass seeds harvested in the unripe condition have a very short period of viability. The data presented partially substantiate this statement so far as the pre-milk and some of the milk stage seeds are concerned. However, seeds collected in the dough stage of the species considered here did not lose their viability more rapidly than mature seeds. Milk stage seeds of *B. marginatus* and *B. polyanthus* and also the pre-milk seeds of the

[4]The very low emergence from *Stripa viridula* seeds was undoubtedly at least partly due to dormancy (also shown in the germination tests), since in the 1939 field planting similar seed gave 21% emergence.

latter species gave as high viability and longevity as those harvested at maturity.

The results of the soil germination tests indicate that for experimental purposes, if seeds were germinated under greenhouse conditions and the plants transferred later to the field, seeds of the species tested might be harvested as early as the dough stage without danger of appreciable loss in a particular strain. However, the field plantings showed that in most instances only mature seeds could be expected to produce good emergence in such plantings. Of the immature seeds, those of the dough stage of *Elymus glaucus* and of the dough and milk stages of *Bromus marginatus* and *B. polyanthus* gave a satisfactory number of seedlings under field conditions the first year after collection. In subsequent field plantings, only the dough stage seeds of *B. marginatus* showed seedling emergence approaching that of mature seeds. The field tests also suggested that under favorable growing conditions, if a seedling appears, its chances for survival and development are about equal whether it be produced by an immature or mature seed. With more unsatisfactory conditions for growth during the early part of the seedling year, it is possible that seedlings from immature seeds would have a greater mortality rate than those from mature seeds.

Since the seeds were all at least 4 months old by the time the first germination test was run, most of them had probably had time to emerge from that period of dormancy common to many freshly harvested seeds. The only definite evidence of dormancy found was one of 9 months duration in the pre-milk seeds of *Elymus glaucus* and a prolonged dormancy in all seeds of *Stipa viridula*. The germination curves for the latter species are interesting since they show that the immature seeds overcame the factors causing dormancy more slowly than mature seeds. Mature seeds gave 89% germination in 15 months, while dough stage seeds required 58 months to attain a viability of 93%. Likewise, the pre-milk seeds increased in germination still more slowly than the dough seeds. Hermann and Hermann (3) found that immature seeds of crested wheatgrass required a longer after-ripening or storage period than mature seeds before good germination could be obtained. Kearns and Toole (4), in a study of factors influencing the germination of *Festuca* species, showed that immature and mature seeds were more dormant immediately after harvest than dead-ripe seeds. In both of these studies, the periods of storage required for after-ripening were relatively short. The dormancy exhibited by the *S. viridula* seeds was of a similar length as described for the internal dormancy of *Oryzopsis hymenoides*, Indian ricegrass, by Huntamer (5). She recommended dry storage of 1 to 2 years to overcome this dormancy in *O. hymenoides*. A storage period of a similar length of time was sufficient to break the dormancy in mature seeds of *S. viridula*.

The possibility has been suggested that grass seed may be harvested in a slightly immature condition and during the curing process in the field complete the necessary translocation of food to mature the seed. Preliminary tests at Logan with dough stage seeds of *Agropyron cristatum* and *Bromus inermis* indicated that there was little in-

crease in weight in seeds allowed to remain on the stalks and cure in the field compared with seeds stripped from the plant and allowed to air-dry without a chance of continued food translocation. During this test, the usual weather conditions common in July of low humidities and high temperatures prevailed. It is reasonable to assume that in localities where the plants dry slowly after cutting, there might be more opportunity for continued ripening of seed after harvest. A more permanent solution to the problem of shattering of grass seed would be the development of strains resistant to shattering such as has been accomplished with the small grains and other crop plants.

SUMMARY

The viability, storage qualities, and vitality of seeds of *Agropyron cristatum*, *A. smithii*, *A. trachycaulum*, *Bromus inermis*, *B. marginatus*, *B. polyanthus*, *Elymus glaucus*, and *Stipa viridula* collected in 1937 in the pre-milk, milk, dough, and mature stages of development were studied. Soil germination tests were conducted under greenhouse conditions after the seeds had been stored for 4, 9, 15, 22, 40, 51, and 58 months. Field plantings were made in 1938, 1939, and 1940 to observe the emergence and vitality of the seedlings produced by seeds of the different stages of maturity.

In the greenhouse tests the pre-milk and milk seeds were inferior in most instances both in viability and longevity to seeds harvested either in the dough or mature stages. Seeds of *Bromus marginatus* and *B. polyanthus* collected in the milk stage and even pre-milk seeds of the latter species, however, gave as high germination during the entire storage period as the mature seeds. Dough stage seeds had similar viability and longevity to the mature seeds in all species. The viability of mature seeds of *Agropyron crsitatum*, *B. marginatus*, and *B. polyanthus* decreased little, if any, in 58 months of storage, while *A. smithii* seeds lost 30%, *A. trachycaulum* 74%, and *B. inermis* 18%. There was a nearly complete loss of viability in all seeds of *Elymus glaucus* in 58 months.

An extended dormancy was observed in the seeds of *Stipa viridula*. Mature seeds overcame this dormancy more quickly than the dough or pre-milk stage seeds. The seeds of this species collected at maturity gave 24% germination 4 months after harvesting and 98% germination 47 months later.

In the field plantings the immature seeds were generally much inferior to those harvested at maturity so far as seedling emergence was concerned. The only immature seeds which gave as large a number of seedlings as the mature seeds during the 3 years following collection of seed samples were those of the dough stage of *Bromus marginatus*. No differences in size or relative survival could be detected by the end of the seedling year between plants produced from mature or immature seeds.

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NOTE

INTERPRETATION OF OLSEN AND SHAW'S FIELD TESTS BY THE MITSCHERLICH-BAULE THEOREM AND THE UNIVERSAL YIELD DIAGRAM

THE recent work of Olsen and Shaw[1] on six Ohio soils contains evidence that tends to confirm the currently accepted Mitscherlich c value (0.33) for the specific effect factor of the growth factor potash. Their figure for this effect factor, 0.34, is the mean of experimental results (pot tests) ranging between 0.26 and 0.49.

They also made a 3-year field experiment on the six soils from which the laboratory soil samples were taken. Their paper, however, contains no discussion of the results of these field experiments in the light of the Mitscherlich-Baule theorem. This omission is regretable, for two reasons. In the first place, their field experiments are an even better confirmation of the Mitscherlich c value for potash than their pot tests. In the second place, these field tests clearly illustrate possible uses of the Mitscherlich-Baule theorem as an agronomic tool.

In Fig. 1 seven of Olsen and Shaw's field experiments are graphed on the universal yield diagram. In six of these tests the fit of the field results on the theoretical curves is seen to be fairly good. (The one apparent exception will be discussed farther on.) These fits offer a substantial confirmation of the potash factor 0.33 and the derived value of 82 pounds, acre basis, for the Baule unit of potash. (By definition,[2] 1 Baule unit of a growth factor is that amount of it that will produce one-half (50%) of the total yield that might be produced by extended application of the growth factor).

The universal yield diagram here shown consists[3] of a series of Mitscherlich curves, numbered 6 to 17, which have been calculated for different values of A (6.0, 6.5, 7.0, 7.5, 8.0, etc.), using the Mitscherlich-Baule universal yield equation $\log (A - y) = \log A - 0.301x$. In this equation 0.301 is the Mitscherlich-Baule constant value of c which is applicable to any growth factor x, when x is expressed in Baule units.

For evaluating a field test by the Mitscherlich-Baule theorem with the object of determining the amount of potash in the soil, it is necessary that yields be expressed in units of dry vegetable substance, and the amount of potash employed in Baule units. Olsen and Shaw report their yields as bushels of corn and pounds of stover. Converting bushels to pounds and adding the result to the weight of stover, we

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[1]OLSEN, S. R., and SHAW, B. T. Chemical, Mitscherlich, and Neubauer methods for determining available potassium in relation to crop response to potash fertilization. Jour. Amer. Soc. Agron., 25:1–9. 1943.

[2]WILLCOX, O. W. A B C of Agrobiology (page 79.)

[3]WILLCOX, O. W. The fertilization of sugar cane. I. A simple graphical method of evaluating tests with fertilizers. Facts About Sugar, 35, No. 12:33–37. II. The agrobiologic evaluation of some potash tests. Sugar, 36, No. 6:26–29, 1941. III. The agrobiologic evaluation of some nitrogen tests. Sugar, 36, No. 11:26–27; 31. 1941.

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get the total yield in pounds. This gives inconveniently large figures, running into thousands of pounds. In order to bring these figures within the range of the diagram, which does not extend vertically above 12 units, the sum of the weights of corn and stover with each of the four graded amounts of potash have been divided by the common factor 800. The yield data, ready for diagramming, then appear as shown in Table 1.

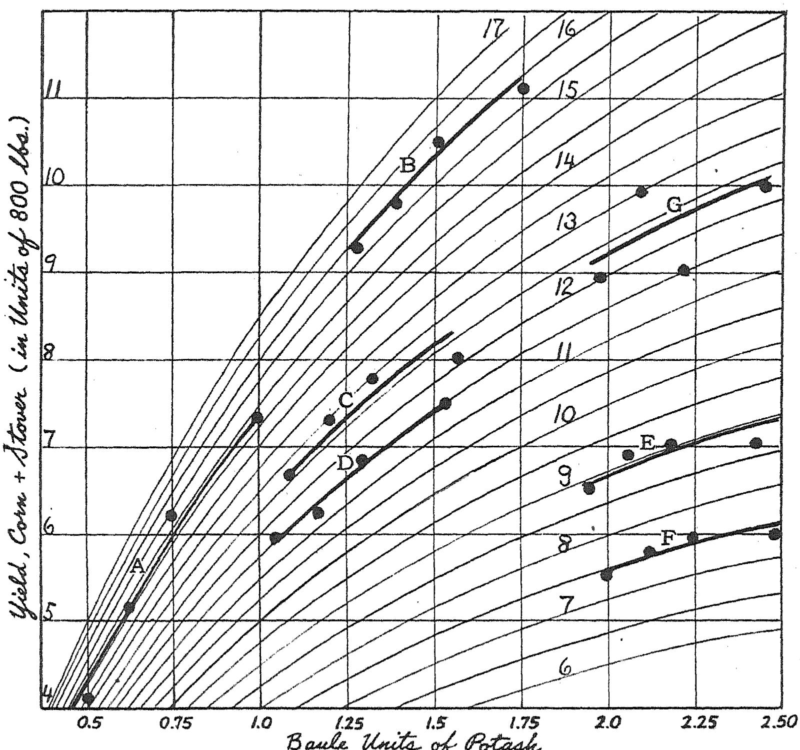

FIG. 1.—The universal yield diagram with seven of Olsen and Shaw's field experiments. A, Clermont silt loam, 1940; B, Miami silt loam, 1939; C, Mahoning silty clay, 1939; D, Wooster silt loam, 1939; E, Muskingum silty clay, 1940; F, Wooster silt loam, 1940; G, Wooster silt loam, 1941.

To convert pounds of potash to Baule units (acre basis), the pounds used are divided by 82. It then appears that Olsen and Shaw used 0, 0.122, 0.244, and 0.488 Baule units as the four graded amounts of this plant nutrient.

The method of using the universal yield diagram to find A and the original potash content of the untreated soil has been described by the writer in the cited publications and it may be here briefly restated, taking the recalculated yield data of the 1939 test on Miami silt loam as an example. The converted yield figures of this experiment are 9.30, 9.84, 10.56, and 11.17. Lay a sheet of transparent paper on a

TABLE 1.—*Yield data.*

Soil	Yield		Soil	Yield		Soil	Yield	
	Pounds	Units		Pounds	Units		Pounds	Units
A	3,229	4.04	B	7,437	9.30	C	5,349	6.68
	4,137	5.17		7,874	9.84		5,891	7.36
	4,976	6.22		8,452	10.56		6,249	7.81
	5,874	7.34		8,935	11.17		6,408	8.01
D	4,783	5.98	E	5,260	6.57	F	4,444	5.55
	4,998	6.25		5,579	6.97		4,665	5.83
	5,472	6.84		5,625	7.03		4,800	6.00
	6,030	7.54		5,676	7.09		4,850	6.06
G	7,165	8.95						
	7,884	9.85						
	7,206	9.00						
	7,892	9.86						

copy of the standard yield diagram. Draw a pencil line over the horizontal line corresponding to the ordinate 9 of the diagram. On any vertical line above this horizontal line make a pencil dot corresponding to the ordinate 9.30. Make another dot 0.122 Baule unit to the right of the first dot corresponding to the ordinate 9.84. Make a third dot 0.244 Baule unit to the right of the first dot to represent the ordinate 10.56, and 0.488 Baule unit to the right locate a dot corresponding to the ordinate 11.17. Now slide the transparent paper back or forth, keeping the penciled horizontal line exactly over the line 9 of the diagram, until the four dots all fall on the same curve, or until imaginary lines connecting the four dots transect the fewest curves. The value of *A* is then given by the number of the curve which shows the closest fit (it may be an intermediate curve).

In this example, the four points make the closest fit with curve No. 16 (heavy black curve B in the figure). *A* in the equation for this experiment is therefore 16; or, since we are dealing with multiples of 800, multiplying 16 by 800 gives 12,800 pounds of combined corn and stover per acre as the maximum yield that might be obtained on this field by using more potash in such a year as 1939. For extrapolating purposes the yield equation becomes $\log (16 - y) = \log 16 - 0.301x$, the x representing Baule units of potash. The whole process of finding *A* is accomplished without any nerve-racking calculations, and with a little practice will not consume more than 3 or 4 minutes. Finding the amount of potash in the untreated soil is just as easy. The ordinate 9.30, representing the yield of the check plots, intersects the axis of abscissas at the point showing 1.275 Baule units (102.5 lbs.) per acre.

The first reaction of an agrobiologist who looks at this steeply rising 1939 yield curve of the Miami silt loam is a perception that here is an otherwise good soil that is relatively poor in potash. The steep rise of the curve is an indication not only of a dearth of potash, but also that the situation as regards other growth factors is excel-

lent. That is, the soil evidently contains a good supply of these other factors, so that added potash can exert a greater effect than it would if some other factor were relatively deficient. The steep slope of this curve also suggests that a larger addition of potash would have produced a further increase of yield. One of the practical uses of the Mitscherlich-Baule theorem is to make an estimate of the probable amount of the expected increase. Suppose that the experimenters, instead of stopping at 40 pounds of potash, had added another 40 pounds, making a total of 2.251 Baule units (including the 1.275 units already present). Substituting 2.251 for x in the equation $\log (16 - y) = \log 16 - 0.301x$, it is found that the 1939 yield from this soil might well have been 12.64 units of dry substance instead of the 11.17 units given by the first 40-pound addition. This would be an increase of 1.47 units, or 1,176 pounds of corn and stover.[4]

Looking at the graph of the 1940 yield of the Clermont silt loam (black curve A), we again get the impression of a relatively good soil that is poor in potash, having only 0.5 Baule unit instead of the 1.275 units of the Miami soil. In the natural order of things the soil with the least amount of original potash is expected to give the largest response to a given amount of this plant nutrient, other things being equal. This is, in fact, the case here. The 40 pounds of potash used by Shaw and Olsen on this soil gave an increase of 3.30 yield units, whereas the same 40 pounds on the Miami soil gave 1.47 yield units.

We can use the yield equation to estimate how much another 40 pounds of potash might have produced on the Clermont soil. The universal yield diagram shows that the A value of this soil for potash is 14.75 yield units and that it contains 0.5 Baule unit of original potash. Making the appropriate substitutions in the universal yield equation, it is found that the yield might have been 9.447 units, an increase of 2.107 units, or 1,655 pounds more of corn and stover. Up to and somewhat beyond this point the Clermont soil might continue to make better use of potash than the Miami soil, but it could never quite catch up. The A value of Miami is 16.00 and the A value of Clermont is 14.75. If we overlook the fact that these two tests were made in different years, the difference between these two A values, 1.25 yield units, would represent a difference of 8.48% in the agronomic quality of these soils in respect of growth factors *other than potash*. Obviously, the Clermont soil is basically less fertile than the Miami soil, still overlooking the difference in years. In the end, Miami would be found giving 8.48% more corn and stover than Clermont.

This comparison of the Miami and the Clermont soils points up another practical use of the Mitscherlich-Baule theorem. The universal yield diagram, which is founded on this theorem, not only indicates how much potash a soil may contain and how much more might well be added, but it also gives a broad hint on what the soil *does not contain*. As was said just above, the Clermont soil is shown to be basically

[4]Provided, that further additions of potash do not create a state of physiological unbalance. Recognition and quantitative evaluation of such cases by the universal yield diagram will be exemplified in a later paper.

less fertile than the Miami soil, and the difference in their overall fertilities is measured by the difference between their *A* values in respect of potash. The Clermont soil is evidently lacking in some growth factor or factors that would bring its *A* value up to that of the Miami soil when it is treated with 40 pounds of potash. In the act of determining the potash content by a field test, which is then evaluated by the universal yield diagram, the agronomist is at the same time acquiring a means for appraising the comparative status of that soil in respect of the general complex of growth factors. By making the test on two neighboring fields under the same meterological conditions the agronomic qualities of these soils may be given fairly accurate numerical ratings. Of course, two neighboring fields may be rated by the routine weights of the crops they produce, but this is not the same as recording their relative efficiencies in standard agrobiologic units. Moreover, the superficial observer who looks only at field weights may easily be deceived.

In the 1939 test with Mahoning silty clay, curve C, and 1939 Wooster silt loam, curve D, these two soils show up with nearly the same original potash contents, *viz.*, 1.09 and 1.05 Baule units, and they have given nearly the same response to potash, *viz.*, 1.33 and 1.58 yield units. Otherwise, however, they are unequal in overall fertility, as their *A* values to potash are 12.7 and 11.5 (different conditions overlooked). The same situation exists between 1940 Muskingum silty clay (E) and 1940 Wooster silt loam (F). These soils have nearly identical potash contents, show practically the same response to added potash, but they have different *A* values, *viz.*, 7.5 and 8.9. Again, it will be noted that the Clermont (A) and the Muskingum silt loam (E) have given nearly the same total yields, *viz.*, 7.34 and 7.09 yield units, after receiving 40 pounds of potash, but the diagram shows that their *A* values are greatly different, *viz.*, 14.75 and 8.9, corresponding to differences in the amounts of growth factors other than potash contained in them. These are examples of deceptive appearances.

Wooster silt loam appears three times in this diagram; D represents the 1939, G the 1940, and F the 1941 tests. All three tests were made on the same plots, and in each of the three years the same amounts of potash were added. D and F show fairly snug fits on their respective *A* curves, but G presents an apparently abnormal picture. After applying analysis of variance to their data, Olsen and Shaw dismiss this test along with several others as statistically not significant. However, as the writer has pointed out, analysis of variance has no practical relevancy in field tests where direct reaction between the plant and the soil is involved. In field tests where the object is to evaluate specific properties of the plants themselves, as in spacing tests, variety comparisons, disease resistance, etc., and where soil variation introduces an extraneous complication, analysis of variance has a certain use. But where an able experimenter makes a field test with due precautions, the average yield of a series of plots under the influence of different amounts of a plant nutrient represents an absolute datum and must be given full weight at its face value. That being the case it is possible, by finding a position on the universal

yield diagram where imaginary lines joining the four points transect the fewest curves, to place this test in its proper agrobiologic setting. The grounds on which the writer bases the foregoing statements have been extensively set forth in another place.[5] The diagram automatically equates the differences in yield between plots and series and assigns to this field, as of 1941, an *A* rating of 12.3. The diagram shows that, on the whole, the addition of potash to this field in that year had a positive action, amounting to about 1 unit of yield.—O. W. Willcox, *Consulting Agrobiologist, 197 Union Street, Ridgewood, N. J.*

[5]See footnote 3.

BOOK REVIEWS

SOIL AND PLANT ANALYSIS

By C. S. Piper. Adelaide, South Australia: University of Adelaide. XIV + 368 pages, illus. 1942. 16s. 6d. postpaid; in Canada, 15s. 9d. postpaid (both amounts in Australian currency).

THIS volume, a laboratory manual of methods for the examination of soils and the determination of the inorganic constituents of plants, is a monograph of the Waite Agricultural Research Institute of the University of Adelaide and the author is the chemist of the Institute. The book aims to bring together methods for chemical examination of the very diverse soils and plants of Australia, methods which not only through experience have proved entirely trustworthy, but which also meet the demands of a growing science of pedology. It covers quite comprehensively not only the usual subjects under such a title, such as soil sampling, hydrogen-ion concentration, mechanical analysis, hydrochloric acid extraction, base exchange, and many others, but also single-value soil constants, soil color, and determination of trace elements.

The book has reference lists after each chapter and separate indices for soils and plants. Anyone dealing with soil and plant analysis should find much of interest and value in the volume. (R. C. C.)

POTASH IN NORTH AMERICA

By J. W. Turrentine. New York: Reinhold Publishing Corp. 186 pages, illus. 1943. $3.50.

THIS volume is a contribution to the monograph series of the American Chemical Society and is written by the president of the American Potash Institute. It not only reviews the work of the past 15 years on the problem of developing an American potash industry, but also outlines foreign developments in the same field. The uses of potash in industry are extensively discussed as well as the technology of production. Practically all phases of this growing American industry are covered and the book, besides its factual matter, makes very interesting reading. Anyone interested in recent developments and methods which have succeeded in giving this country potash independence will find the volume worthwhile. (R. C. C.)

AGRONOMIC AFFAIRS

MEMBERS OF THE AMERICAN SOCIETY OF AGRONOMY SERVING IN THE ARMED FORCES

PRACTICALLY every member of the American Society of Agronomy is assisting in the war effort of his country in some capacity. Certain individuals are contributing the most by continuing in the work they have been doing for many years, others are contributing the most by entering specialized fields of production, others are making their greatest contribution in technical fields requiring

specialized training, and still others are making their greatest contribution by serving with the armed forces.

It is the group of members of the Society serving with the armed forces that deserve special recognition. The Historian has been advised that the following men are eligible for this recognition. It is recognized that the list is not complete, and therefore, another list of names will be published at a later date.

ACCOLA, ROBERT C., SCS, Cederedge, Colorado
ANDREW, LOUIS E., SCS, Vista, California
AULT, C. H., SCS, Boise, Idaho
BATCHELOR, HAROLD W., Ohio State University, Columbus, Ohio
BELCHER, B. A., Bureau of Plant Industry, U.S.D.A., Cairo, Georgia
BIEBERDORF, FRED W., University of Minnesota, St. Paul, Minn.
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BROADFOOT, W. M., West Virginia University, Morgantown, W.Va.
CARPENTER, R. W., SCS, Mandan, North Dakota
CHANDLER, WILLIAM V., North Carolina State College, Raleigh, N. C.
CLARK, RALPH K., SCS, Waterloo, Iowa
CLYMER, JOHN A., SCS, Syracuse, Nebraska
COLGON, JOE M., SCS, Spirit Lake, Iowa
DEROSE, H. ROBERT, Massachusetts State College, Amherst, Mass.
DOUGLAS, DONALD S., SCS, Waterville, Washington
DRAKE, MACK, Purdue University, Lafayette, Indiana
DUKEE, HUGH, SCS, Marianna, Florida
DUKES, HUGH, University of Florida, Gainesville, Florida
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HOLT, MANARD E., SCS, Eutaw, Alabama
HOOD, CHARLES M., SCS, Baraboo, Wisconsin
HUTTON, CURTIS E., Harve de Grace, Maryland
JAMES, CLIFFORD L., Oakboro, North Carolina
JOHNSTON, THEODORE H., University of Nebraska, Lincoln, Nebr.
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Naftel, James A., Alabama Polytechnic Institute, Auburn, Ala.
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Peck, Walter T., SCS, Chinook, Montana
Pederson, Marion W., University of Nebraska, Lincoln, Neb.
Phillipe, Paul M., Ohio State University, Columbus, Ohio
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Reagan, M. H., University of Minnesota, St. Paul, Minn.
Rogers, Alton B., SCS, Royston, Georgia
Sander, Albert F., SCS, Caliente, Nevada
Schmaltz, Bruce, Utah State Agricultural College, Logan, Utah
Schmitt, C. G., University of Arkansas, Fayetteville, Arkansas
Sherwood, L. V., University of Illinois, Urbana, Ill.
Shrader, W. D., University of Missouri, Columbia, Mo.
Sieling, Dale H., Massachusetts State College, Amherst, Mass.
Smartt, Edward R., Lamar, Colorado
Smith, Dale, University of Nebraska, Lincoln, Nebraska
Smith, Orlie, Montana State College, Bozeman, Montana
Spencer, J. F., University of Kentucky, Lexington, Ky.
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Sprague, M. A., University of Arkansas, Fayetteville, Ark.
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Watts, J. B., Soil Conservation Service, Shelby, N. C.
Weihing, Ralph M., Colorado State College, Fort Collins, Colo.
Weiss, Martin G., Bureau of Plant Industry, U.S.D.A., Ames, Iowa
Weldon, Marcus D., University of Nebraska, Lincoln, Nebr.
Whitney, Robert S., Colorado State College, Fort Collins, Colo.
Willkie, R. L., University of Kentucky, Lexington, Ky.
Woodruff, C. M., University of Missouri, Columbia, Mo.
Zuber, M. S., Bureau of Plant Industry, U.S.D.A., Ames, Iowa.

R. I. Throckmorton, *Historian.*

THE 1943 MEETINGS

PLANS are well under way for the 1943 meetings of the American Society of Agronomy and the Soil Science Society of America. Cincinnati has been selected as the meeting place with the Netherland-Plaza Hotel as headquarters. The dates have been set for November 10 to 12, inclusive.

The general program of the American Society of Agronomy will be held on Thursday morning, November 11. A new departure this year will be a combined banquet of the American Society of Agronomy and the Soil Science Society of America on Thursday evening. At that time the President of the American Society of Agronomy will deliver his address. For the Soil Science Society of America, the speaker will

be Howard M. Call, Ohio farmer and brother of Director Leland Call of the Kansas Agricultural Experiment Station, whose subject will be "The Old Home Farm, One Hundred and Forty Years Ago and Now".

Preliminary plans for the meeting of the Crops Section of the American Society of Agronomy are announced by the Chairman of the Crops Section Program Committee, Doctor L. F. Graber, College of Agriculture, Madison, Wis. Several sessions will be arranged for contributed papers. Presentation of the results of current research having a bearing on the war effort are most desirable and are solicited. Those wishing to present papers are requested to send the title to the Chairman of the Section before August 15.

Arrangements are now being made for a grassland improvement conference, a symposium on soft wheat breeding, a section on the industrial utilization of crops, a soybean improvement conference, a section on research on fiber crops in a wartime agriculture, a conference on extension participation, and a general program on agronomic contributions and their current significance.

Doctor Firman E. Bear, President of the Soil Science Society of America, announces that in addition to the usual Sectional programs, the Society will hold two general sessions. The first of these is scheduled for Wednesday evening to replace the banquet and will comprise a symposium on "Commemorating the One-hundredth Anniversary of the Founding of the Rothamsted Experiment Station". The second will deal with "Efficient Use of Fertilizers During the War in Relation to the Major Soil Groups".

Those desiring to present papers before one or another of the six Sections of the Soil Science Society should get in touch with the respective chairmen of these Sections as soon as possible. These chairmen are as follows: Section I, Soil Physics, G. W. Conrey, Ohio State University, Columbus, Ohio; Section II, Soil Chemistry, Hans Jenny, University of California, Berkeley, Calif.; Section III, Soil Microbiology, H. W. Reuszer, Alabama Polytechnic Institute, Auburn, Ala.; Section IV, Soil Fertility, B. A. Brown, University of Connecticut, Storrs, Conn.; Section V, Soil Genesis, Morphology, and Cartography, R. E. Storie, University of California, Berkeley, Calif.; and Section VI, Soil Technology, J. S. Owens, University of Connecticut, Storrs, Conn.

PASTURE INVESTIGATIONS TECHNIC

A PRELIMINARY report on pasture investigations technic has been prepared by a joint committee representing the American Society of Agronomy, the American Dairy Science Association, and the American Society of Animal Production and has been published in the April issue of the JOURNAL OF DAIRY SCIENCE.

Those who are interested in the subject but who do not have access to the JOURNAL OF DAIRY SCIENCE are invited to write to R. H. Lush, Chairman, Pasture and Range Committee, American Society of Animal Production, the National Fertilizer Association, 616 Investment Building, Washington, D. C., where reprints may be obtained.

NEWS ITEMS

DOCTOR W. A. LEUKEL, agronomist with the Florida Agricultural Experiment Station for the past 17 years, died suddenly at his home on April 27 and was buried at Marshfield, Wis., near his birthplace. Doctor Leukel's researches with Florida grasses and crops made him widely known both among Florida cattlemen and farmers and in scientific circles.

—A—

ACCORDING to a dispatch to the New York TIMES, Doctor Alexander P. Anderson, credited as being the originator of puffed cereals, died in Miami, Fla., on May 7th at the age of 80.

JOURNAL

OF THE

American Society of Agronomy

VOL. 35 JUNE, 1943 NO. 6

FACTORS INFLUENCING SEED SETTING IN SEVERAL SOUTHERN GRASSES[1]

GLENN W. BURTON[2]

THE seeding habits of a grass greatly influence its natural distribution, its ease of establishment, and its usefulness in improving pastures. The excellent seeding habits of carpet grass, *Axonopus affinis*, have been an important factor in the widespread use of this grass in the Southeast. Several of the highly productive *Digitaria* species from South Africa are not being used in this area because they spread slowly and produce very little seed. Florets develop in these Digitarias, but a large percentage fail to set seed.

So far as the author is aware no previous attempts have been made to study experimentally the factors affecting seed setting in pasture grasses adapted to the humid South. Several workers, including Evans and Calder (5),[3] Evans (4) and DeFrance and Odland (3), have studied the influence of fertilizer mixtures upon seed yields of several of the northern grasses. They agree that generally seed yields may be increased by moderate applications of nitrogen and that phosphorus and potassium have negligible effects upon yields either alone or with nitrogen. They make no reference, however, to the influence of these materials upon the percentage of florets to set seed.

MATERIALS AND METHODS

In March, 1937, an experiment was set up to determine the influence of five different fertilizers upon seed setting in 10 southern grasses. Plots 4 × 4 feet separated by 1-foot alleys were laid out on a Tifton sandy loam and were fertilized with the fertilizers listed in Table 1 at a rate of 800 pounds per acre. Manure at the rate of 20 tons per acre was incorporated into the soil of the manured plots before the grass was planted. In 1939 and 1940 these manured plots received 800 pounds per acre of 4–10–6 in March and two 100-pound per acre topdressings of nitrate of soda at intervals during the summer. All other plots received the basic 800-pound application of fertilizer each spring for the duration of the experiment.

[1]Cooperative investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the Georgia Coastal Plain Experiment Station, and the Georgia Experiment Station, at Tifton, Georgia. Received for publication October 26, 1942.

[2]Geneticist, U. S. Dept. of Agriculture, Tifton, Ga.

[3]Figures in parenthesis refer to "Literature Cited", p. 474.

The following 10 grasses were planted in quadruplicate in early April 1937: Woollyfinger grass, *Digitaria eriantha*, P. I. 77998; woollyfinger grass, *Digitaria eriantha* ,P. I. 106663; woollyfinger grass, *Digitaria* sp., P. I. 111128; Dallis grass, *Paspalum dilatatum;* Bahia grass, *Paspalum notatum;* ribbed paspalum, *Paspalum malacophyllum;* carpet grass, *Axonopus affinis;* and three strains of Bermuda grass, *Cynodon dactylon*, common, Tift, and P. I. 105933. The common Bermuda grass plots were seeded at a heavy rate with commercial seed harvested in Arizona. All of the other grasses were established by planting vegetative material from clones representative of each strain.

Most of the grasses in this test head continuously for periods ranging from 1 to 4 months each summer (2). In order to determine the seasonal variations in seed setting in these grasses, seed samples were taken from each plot at weekly intervals. Only heads which possessed ripe seeds but green peduncles (stem of the inflorescence) were harvested. Preliminary studies revealed that in such heads anthesis occurred from 3 to 4 weeks prior to the date of harvest. Thus, it was possible to obtain from meteorological records the weather conditions that prevailed during the anthesis of each seed harvest.

Only grass heads were removed in the sampling procedure. The leaves and plant residue that accumulated during the growing season were burned on the plots each winter before new shoots appeared.

Seed setting was measured by determining the percentage by weight of the total florets in any sample that contained caryopses. Threshing separated the florets from the straw but did not remove the caryopses from the florets of any of the grasses in this test. A description of the procedure follows. All florets were removed from each sample in a small nursery thresher and were separated from the straw and dust with hand dockage screens of suitable size. The empty florets were removed from a known quantity (usually 1 gram) of these florets with the aid of a seed blower previously described (1). The empty florets of Dallis grass and woollyfinger grass were easily separated after the hairs on the glumes had been singed off with a blow torch. The remaining florets that contained caryopses were then weighed on a chainomatic balance and their percentages by weight were calculated.

RESULTS

SEED SETTING AND SOIL TREATMENT

The influence of soil treatment upon the percentage of florets to set seed in these grasses for the period 1937 to 1940, inclusive, is presented in Table 1. Each weekly determination was given equal weight in arriving at the averages included in this table. These data indicate that fertilization had no significant effect upon seed setting in these 10 grasses.

Since the Tifton sandy loam upon which this experiment was conducted was in a good state of fertility, it seemed desirable to determine whether or not similar results might be obtained on a soil of low fertility. Therefore, in 1941, a number of different fertilizer mixtures were applied at the equivalent rate of 1 ton of 4–8–4 per acre to small plots of Bahia grass growing on a poor soil. The treatments consisted of a check receiving no treatment and fertilizer mixtures containing all, and all but one of each of the following elements: N, P, K, Ca, S, Mg, Cl, and Na, making nine fertilizer combinations in all. The same quantities of each element were included in each

mixture containing that element. Each treatment was replicated four times. A study of the percentage of florets by weight produced on these plots in 1941 revealed that the large variations in the quantity and balance of the fertilizer mixtures used in this test did not influence the percentage of Bahia grass florets to set seed.

TABLE 1.—*The influence of soil treatment upon the percentage of florets to set seed in 10 southern grasses for the period 1937 to 1940, inclusive.*

Grass	No. of weekly determinations	Percentage of florets by weight containing caryopses when fertilized with					
		0–0–0	0–10–0	0–10–6	Manure + 0–10–6	4–10–6	Average
Woollyfinger grass, P. I. 77998	10	4.1	1.7	1.4	1.6	2.2	2.2
Woollyfinger grass, P. I. 106663	9	4.3	5.9	4.0	4.6	4.4	4.8
Woollyfinger grass, P. I. 111128	21	9.2	9.0	6.3	4.6	5.7	7.0
Dallis grass*	36	48.7	47.4	45.8	46.9	45.7	46.9
Bahia grass	44	71.7	70.8	70.1	69.9	69.9	70.6
Ribbed paspalum	35	37.5	35.6	34.2	34.5	31.6	34.6
Carpet grass	28	72.0	71.2	73.8	60.7	70.5	69.6
Bermuda grass, P. I. 105933	34	35.1	37.4	38.5	39.6	37.3	37.4
Bermuda grass, Tift	16	28.8	30.0	31.0	29.9	29.9	30.0
Bermuda grass, common	50	51.5	50.7	50.9	55.9	53.7	52.5

*These percentages include florets containing caryopses and ergots. Separations of these components for 1939 and 1940 are shown in Table 6. For details of fertilizer treatments see text.

SEED HEAD ABUNDANCE AND SOIL TREATMENT

In 1939 the number of heads on each plot of the 10 different grasses were counted just prior to the first seed harvest of each grass. A summary of these counts appears in Table 2. The least significant 5% mean difference has been calculated for each grass and is presented in Table 2 to assist in its interpretation. It is evident from these data that the application of phosphorus and potassium without nitrogen produced significant increases in the number of heads in only one grass, common Bermuda. The addition of nitrogen to the basic phosphorus and potash treatment usually increased the production of seed heads materially. This is illustrated in Fig. 1. Notable exceptions were the P.I. 105933 strain of Bermuda grass which failed to respond significantly to any treatment and carpet grass receiving 4–10–6 (all inorganic) with no additional nitrogen topdressings.

The treatment 4–10–6 + N, in which the March 4–10–6 application was followed with nitrogen topdressings later in the season, greatly stimulated carpet grass head production. Table 3 shows that carpet grass started to head much later than any other grass in this test. Thus, it appears that inorganic nitrogen applied far in advance

FIG. 1.—The influence of fertilizer upon the number of seed heads produced by Ribbed Paspalum, July 20, 1939. Left to right, no fertilizer; 4–10–6 plus N; 0–10–0; 4–10–6; and 0–10–6.

of the blooming period will not stimulate seed head production in carpet grass. This is probably due to the fact that the nitrogen is tied up in the rapidly growing plant before the flower primordia are initiated.

TABLE 2.—*The influence of soil treatment upon the number of seed heads produced by 10 southern grasses at the time of the first seed harvest in 1939.**

Grass	Number of heads produced per 4 × 4 foot plot when fertilized with					Least significant 5% mean difference
	0–0–0	0–10–0	0–10–6	4–10–6 + N	4–10–6	
Woollyfinger grass, P. I. 77998	6	5	6	24	20	8.6
Woollyfinger grass, P. I. 106663	4	3	5	11	6	6.9
Woollyfinger grass, P. I. 111128	49	63	84	159	148	58.0
Dallis grass	49	75	75	157	159	34.6
Bahia grass	405	372	361	650	576	87.7
Ribbed paspalum	129	138	129	391	335	39.4
Carpet grass	376	343	244	611	279	86.9
Bermuda grass, P. I. 105933	108	129	108	147	133	†
Bermuda grass, Tift	45	47	39	68	57	19.8
Bermuda grass, common	48	81	79	148	131	23.1
Average of all grasses	121.9	125.6	113.0	236.6	184.4	

*For details of fertilizer treatments see text. The treatment 4–10–6 + N is listed in Table 1 as manure + 0–10–6.
†Not significant according to the "F" test.

SEED SETTING AND CLIMATE

The weekly variations in the percentage of florets to set seed in 1939 appear in Table 3. This table shows the season when each grass may be expected to mature seed and indicates the extent of the fruiting period. Although weekly fluctuations in seed setting occurred in all of the grasses, the most striking feature of these observations was the decline in seed setting with the advance in season. In an effort to measure the significance of this seasonal decline, the seed setting percentages for 1938, 1939, and 1940 were broken up into three equal or

TABLE 3.—*Weekly variations in the percentage of florets to set seed in ten southern grasses in 1939.**

Grass	Percentage of florets by weight containing caryopses																	
	May 31	June				July				August					September			
		7	14	21	28	5	12	19	26	2	9	16	23	30	6	13	20	27
Woollyfinger grass, P. I. 77998	..	..	..	..	1	7	.3	..	..	..	..	..	..	..	..	..	..	..
Woollyfinger grass, P. I. 106663	..	..	..	..	9	11	3	..	..	..	..	..	..	..	..	..	..	..
Woollyfinger grass, P. I. 111128	..	..	..	3	5	19	5	4	6	8	4	2	..	..	..	..	..	..
Dallis grass	54	30	33	50	36	..	..	69	54	63	74	53	57	58	..	..	..	..
Bahia grass	..	..	..	..	86	83	81	84	78	77	84	74	69	67	77	60	61	54
Ribbed paspalum	..	..	..	56	52	57	62	59	53	39	29	..	..	..	..	..	..	..
Carpet grass	..	..	..	..	..	..	..	90	82	83	80	78	78	72	59	46	49	..
Bermuda grass, P. I. 105933	..	..	72	72	69	62	59	54	41	40	38	..	..	..	..	..	..	..
Bermuda grass, Tift	..	..	53	46	49	44	43	38	13	..	..	..	..	..	..	..	..	..
Bermuda grass, common	86	92	84	85	79	67	73	53	39	53	31	30	25	31	..	..	..	..

*Each percentage value listed above is the average of the analyses of samples taken from the 20 plots of each grass. The percentages for *Paspalum dilatatum* include florets containing both caryopses and ergots. Separations of these components are shown in Table 6.

near equal parts, *viz.*, early, midseason, and late. The averages for these periods, together with the least significant 5% mean differences for each grass, appear in Table 4.

TABLE 4.—*Seasonal variations in the percentage of florets to set seed in seven southern grasses for the period 1938 to 1940, inclusive.*

Grass	Average percentage of florets by weight containing caryopses in samples harvested			Least significant 5% mean difference
	Early	Midseason	Late	
Woollyfinger grass, P. I. 111128*	7.4	6.7	7.8	†
Bahia grass	78.5	73.2	62.1	6.2
Ribbed paspalum	36.8	39.3	22.8	6.5
Carpet grass	83.9	72.7	54.6	6.3
Bermuda grass, P. I. 105933	42.4	34.2	25.7	7.6
Bermuda grass, Tift*	40.6	33.5	26.5	†
Bermuda grass (commercial)	78.6	58.2	23.1	6.7

*Average of 1939 and 1940 data.
†Seasonal differences were not significant according to the "F" test.

Dallis grass and two of the woollyfinger grasses were not included in this study because of the ergot in the former and the limited number of observations obtained from the latter. From the arrangement of the data presented in Table 4 it is evident that Bahia grass, carpet grass, and the two Bermuda grasses, common and P.I. 105933, set more seed in the first third (early) of their fruiting period than during

the second third (midseason) and more during the second third than in the last third (late) of their seeding period. Ribbed paspalum set seed equally well for the first two thirds of the fruiting period but dropped off significantly in the last third. The seasonal variations in Tift Bermuda, although similar to those observed in the other Bermudas, did not differ significantly. Woollyfinger grass P.I. 111128 set seed equally well throughout the three periods arbitrarily chosen in this study.

In an effort to explain the seasonal variations, the weather data accumulated at Tifton in 1938, 1939, and 1940 were grouped and analyzed in conjunction with the seed setting response of each grass. During this 3-year period the florets harvested in the early period bloomed in clearer, cooler, drier weather than those harvested in midseason. Likewise, those florets harvested in midseason bloomed in clearer, cooler, drier weather than those harvested in the late period. Since temperature, cloudiness, and rainfall tended to increase while the percentage of seed set generally decreased, it appeared that these features of the environment might be in part responsible for the seasonal decline in the seed set observed.

An analysis of the weekly fluctuations in seed set, however, revealed that deviations in seed set below normal were not generally associated with the increase in temperature, rainfall, and cloudiness. In common Bermuda grass, for example, there were 10 weeks during the early or midseason periods in this 3-year period when the average temperatures were above the means obtained in the late period. In 8 of these 10 weeks the seed set for the week was equal to or above the average for the period. Similar reactions to rainfall and cloudiness were observed. The failure of these features of the environment to influence seed set from week to week suggests that the actual seed set of florets blooming at any one time is not influenced by fluctuations in temperature, cloudiness, and rainfall of the magnitude experienced in this study.

The average annual percentage of florets to set seed in these grasses during the years 1937 to 1940, inclusive, are presented in Table 5. Since 1937 was the year in which the grasses were planted, somewhat different results than those obtained from well-established sods might be expected. All of the grasses but ribbed paspalum and woollyfinger grass P.I. 111128 set a lower percentage of seed in 1937 than they averaged for the three succeeding years. The results for the years 1938 to 1940 indicate that Dallis grass, Bahia grass, common Bermuda grass, and carpet grass may be expected to set seed well every year. Ribbed paspalum, generally a good seeder, may set little seed in some years. The woollyfinger grasses and the two Bermudas, P.I. 105933 and Tift, appear to be the poorest and least dependable seeders in this group of grasses.

In 1938 Tift Bermuda grass produced very few seed heads and only 0.8% of the florets harvested contained caryopses. In 1939 it produced many heads and 41.0% of the florets harvested from these heads contained caryopses. Bermuda grass P.I. 105933 seeded poorly in 1938 but seeded well in 1939 and 1942. Tift Bermuda produced practically no seed heads in 1942. Since common Bermuda grass set

seed well and headed profusely each year, it is apparent that striking strain differences in the fruiting habits of Bermuda grass exist.

TABLE 5.—*The annual average percentage of florets to set seed in 10 southern grasses for the period 1937 to 1940, inclusive.*

Grass	Average percentage of florets by weight containing caryopses in samples harvested in				Significance of annual variations	
	1937	1938	1939	1940	1937 to 1940	1938 to 1940
Woollyfinger grass, P. I. 77998	0.3	Failed to head	2.8	3.8	**	None
Woollyfinger grass, P. I. 106663	0.1	do	7.5	7.2	**	None
Woollyfinger grass, P. I. 111128	6.5	do	6.5	5.3	None	None
Dallis grass	35.1	40.0	56.5	46.7	‡	‡
Bahia grass	48.4	72.5	74.5	68.7	**	None
Ribbed paspalum†	44.3	16.5	51.0	40.2	**	**
Carpet grass	56.2	69.5	72.0	71.9	None	None
Bermuda grass, P. I. 105933	13.2	3.5	57.0	60.0	**	**
Bermuda grass, Tift	8.1	0.8	41.0	26.2	**	**
Bermuda grass, common	28.7	50.5	59.5	51.9	**	*

*Exceeds the 5% point.
**Exceeds the 1% point.
†The percentages for *Paspalum dilatatum* include florets containing caryopses and ergots. Separations of these components for 1939 and 1940 are shown in Table 6.
‡Not determined.

ERGOT AND SEED SETTING IN DALLIS GRASS

Ergot, *Claviceps paspali*, is a parasitic fungus that attacks the florets of Dallis grass throughout the South, forming an abundance of sticky "honey dew" and many sclerotia. This disease is generally considered responsible for the poor quality of domestic Dallis grass seed.

In an effort to measure the influence of climate and soil treatment upon the formation of ergot sclerotia in Dallis grass, the following study was made. After the empty florets had been removed from each sample harvested in the seed setting experiment in 1939 and 1940, those florets containing ergots were separated by hand with the aid of a sharp scalpel. These florets were then weighed and the percentage by weight of the full florets containing ergots was calculated. A summary of the results of this study appears in Table 6.

Statistical analyses of these data indicate that soil treatment had no effect upon the amount of ergot formed. Significant weekly variations did exist, however, and after the epidemic set in there was a higher percentage of ergot produced in 1940 than in 1939.

It is interesting to note that ergot first appeared in samples harvested on June 14 in 1939 but was not found in 1940 until the July 12 harvest. This delay in 1940 appears to be associated with an unusually dry period in late April and May which probably prevented the germination of the soil-borne sclerotia necessary for the initial infection.

TABLE 6.—*The influence of climate and soil treatment upon the formation of ergot sclerotia in Dallis grass.**

Fertilizer treatment	Percentage of full florets containing ergot sclerotia†																Average of last 10 harvests
	May	June				July				August					Sept.		
	31	7	14	21	28	5	12	19	26	2	9	16	23	30	6	13	
1939																	
0–0–0	0	0	20	52	15	..	..	58	67	72	55	63	66	47	..	..	51.5
0–10–0	0	0	12	50	17	..	..	42	76	72	52	60	70	59	..	..	51.0
0–10–6	0	0	27	53	26	..	..	20	66	70	61	66	53	67	..	..	50.9
4–10–6 + N	0	0	9	45	26	..	..	14	49	65	68	59	73	52	..	..	46.0
4–10–6	0	0	12	51	31	..	..	22	60	60	52	71	52	53	..	..	46.4
Average	0	0	16	50	23	..	..	31	64	68	58	64	63	56	..	..	49.2
1940																	
0–0–0	..	0	0	0	0	0	9	48	80	61	65	82	86	70	44	51	59.2
0–10–0	..	0	0	0	0	0	0	60	62	61	64	68	78	61	51	49	55.4
0–10–6	..	0	0	0	0	0	13	45	83	59	47	87	74	75	56	54	59.3
4–10–6 + N	..	0	0	0	0	0	4	45	82	52	61	79	89	65	39	46	56.2
4–10–6	..	0	0	0	0	0	2	53	79	68	62	77	81	67	40	46	57.5
Average	..	0	0	0	0	0	6	50	77	60	60	79	82	68	46	49	57.6

*The least significant mean difference at the 5% point between weekly averages = 11.4, between treatment averages = 8.2, and between yearly averages = 3.6. For details of fertilizer treatments see text.

†Florets containing either caryopses or ergot sclerotia.

The total rainfall for the 10 weeks when the ergot-infected florets were blooming was 9.09 inches in 1939 and 17.54 inches in 1940. This probably explains why there was a greater percentage of ergots in 1940 than in 1939.

In the 18 average weekly ergot percentages in 1939 and 1940 (the first analyses in each year was omitted from this consideration), there occurred six significant weekly changes. In all but one of these changes an increase in the percentage of ergots was associated with a marked increase in rainfall during the week of blooming and a decrease in the percentage of ergots accompanied a striking decrease in the rainfall during the week in which the florets bloomed.

The 18 average weekly ergot percentages referred to above may be divided upon the basis of their abundance into two groups with the low ergot group containing the four percentages below the median in 1939, the median and four percentages below it in 1940 and the high ergot group containing the remaining nine observations. If corresponding weekly percentages of the total florets containing caryopses are calculated and averaged, the low ergot group averages 29.6 and the high ergot group averages 18.5. Thus, in 1939 and 1940, it appears that Dallis grass set 60% more caryopses when ergot infection was low than when it was high. This will be given further consideration in the discussion that follows.

DISCUSSION

Since the percentage of florets that set seed at any one time remained fairly constant regardless of soil treatment, fertilizers that increase seed head production in the 10 grasses without decreasing head size should also increase seed yields. Likewise, the number of heads counted at any one time per unit area in plots of these grasses receiving different fertilizer treatments should give a good index of the relative influence of each treatment upon seed yield. It is believed, therefore, that the head abundance counts presented in Table 2 are indicative of the relative effect of each treatment upon the seed yields of the grasses listed.

The influence of ergot upon seed setting in Dallis grass is difficult to measure. Evidence has been presented which indicates that as ergot increases the percentage of florets setting seed decreases. Therefore, ergot appears to reduce the percentage of seed set in this grass. Since the writer has found that emasculated, unfertilized florets will develop ergot sclerotia when inoculated with ergot honeydew, it is evident that fertilization is not required for ergot to attack a floret successfully and to develop a sclerotia. The abundance of ergot that may be found on some of the highly sterile *Paspalum* species hybrids recently produced at Tifton lends additional weight to this conclusion.

Whether or not ergot will attack and destroy florets that have started to develop caryopses has not been proved. Even during the heaviest natural epidemics of ergot at Tifton some caryopses have always been produced. Since these heads were a mass of ergot honey dew a few days after they bloomed, all of the florets should have been well inoculated while the caryopses were still very small. The fact that some caryopses were always produced suggests that only those florets attacked at the time of blooming or soon thereafter were destroyed by ergot.

SUMMARY

1. The influence of fertilizer mixtures, climate, and ergot upon seed setting (the percentage of florets by weight containing caryopses) in 10 southern grasses was studied for the period of 1937 to 1940, inclusive.

2. Fertilization had no significant effect upon seed setting in the 10 grasses growing on a soil of good initial fertility.

3. Large variations in the quantity and balance of fertilizer materials applied to a poor soil did not influence the percentage of Bahia grass florets to set seed.

4. The application of phosphorus and potassium without nitrogen significantly increased the number of heads in only one grass, common Bermuda. The addition of nitrogen to the basic phosphorus and potash treatment materially increased the production of seed heads in most of the grasses studied. Since seed setting did not vary significantly with treatment, head counts were a good index of the influence of each treatment upon seed yields.

5. Although weekly fluctuations in seed setting occurred in all of the grasses, they were generally not great and could not be associated

with rainfall, cloudiness, or temperature variations recorded during the course of this study.

6. For the 3-year period, 1938–40, there was a noticeable decline in seed setting with the advance in season in Bahia grass, carpet grass, the Bermuda grasses, and ribbed paspalum. The woollyfinger grass P.I. 111128 set seed equally well throughout the season.

7. This study indicates that Dallis grass, Bahia grass, carpet grass, and common Bermuda grass may be expected to seed well every year and ribbed paspalum most years. The woollyfinger grasses and the two Bermuda grass strains, P.I. 105933 and Tift, were the poorest and least dependable seeders in this group of grasses.

8. Significant seasonal differences in the seed setting behavior of different strains of Bermuda grass were observed.

9. Weekly and annual variations in the percentage of ergot sclerotia in Dallis grass seed exceeded the minimum required for statistical significance.

10. In most instances increases in the percentage of ergot sclerotia were associated with increases in rainfall at the time of flowering. Likewise decreases in ergot accompanied decreases in rainfall at the time of flowering.

11. Evidence was presented which indicates that as ergot in Dallis grass increases the percentage of florets setting seed decreases. This indicates that ergot does reduce the percentage of seed set in Dallis grass.

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EFFECT OF SOIL AND SOIL TREATMENT ON STABILITY OF CROP PRODUCTION[1]

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YEAR-BY-YEAR variation in crop yields is a well-recognized fact. Society in general, and the farmer in particular, would be greatly benefited if such variation could be reduced.

In previous analyses of the Illinois experiment field data it was found that under most conditions soil treatment practices reduced the annual yield variation of wheat (1)[3] and of corn (2). The purpose of this paper is to present the results of a similar study involving the crop rotation rather than specific crops.

SOURCE OF DATA

The crop yield data used were secured from 10 of the soil experiment fields operated by the Illinois Agricultural Experiment Station. Three of these fields were located in southern Illinois, three in central Illinois, and four in the northern part of the state. The soil of each field is representative of one of the major soil groups of the state as described below.

Soil group	Town	County	Soil description
1	Aledo	Mercer	Very dark, moderately heavy soils with moderately permeable subsoils.
2	Hartsburg	Logan	Very dark, heavy soils with moderately permeable subsoils.
3	Kewanee	Henry	Dark soils with moderately permeable subsoils.
4	Mt. Morris	Ogle	Moderately dark soils with moderately permeable subsoils.
5	Carlinville	Macoupin	Moderately dark soils with grayish cast, slowly permeable subsoils.
6	Joliet	Will	Dark soils with slowly permeable subsoils, carbonates shallow.
7	Ewing	Franklin	Gray, strongly leached soils with very slowly permeable subsoils.
10	Enfield	White	Yellowish-gray, strongly leached soils with slowly permeable subsoils.
14	Oquawka	Henderson	Light brown sands and loamy sands with slight subsoil development.
16	Elizabethtown	Hardin	Yellow soils with slowly to moderately permeable subsoils.

These fields were established during the years 1910–17, primarily to study the effect of soil treatment practices on crop yields. Now, after many years of regular rotation cropping, they also provide information as to the stability or regularity of production under varying seasonal conditions. The crop yield data used in this analysis are those for the 16-year period 1926–41, and include the drought years of 1934 and 1936 as well as a variety of other weather extremes.

The fields were laid out so that each crop in the rotation was represented each

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[3]Figures in parenthesis refer to "Literature Cited", p. 481.

year. On most fields a 4-year rotation was followed; hence the 16-year interval permitted the recurrence of each crop four times on each series of plots. The rotations included the common cornbelt crops and were adjusted to fit the soil conditions at each field.

Most of the plots are a 1/10-acre in size, though there are a few 1/5-acre and a few 1/20-acre plots.

During the 16-year period studied, slight variations in methods of handling occurred on most of the fields. In some instances rotations were modified. Changes were also made in crop varieties, including the use of hybrid corn during the last few seasons.

SOIL TREATMENT

Similar soil treatment systems are used on all fields as follows:

Plot No.	Symbol	Soil treatment
1	Check	None
2	M	Manure
3	ML	Manure, limestone
4	MLP	Manure, limestone, rock phosphate
5	Check	None
6	R	Crop residues
7	RL	Crop residues, limestone
8	RLP	Crop residues, limestone, rock phosphate
9	RLPK	Crop residues, limestone, rock phosphate, potash

Manure is applied once during each rotation in amounts equal to the weight of the crops removed; crop residues consist of cornstalks, grain straws, second-growth clover, and a legume catch crop (usually sweet clover) wherever it can be conveniently used in the rotation; limestone is applied as needed; large applications of rock phosphate were made during the first few rotations and potash is regularly used.

EXPERIMENTAL RESULTS

Acre yields of all crops have been reduced to a common denominator of value in terms of dollars so that direct comparisons can be made between the earning abilities of different soils and soil treatments. Prices of $1.00 a bushel for wheat, 50 cents a bushel for corn, 30 cents a bushel for oats, and $10.00 a ton for hay were assumed. These prices, when applied to the acre yield of each crop each year, give the annual production per acre per year for any given soil or treatment.

The 16-year average production level for each treatment on each field was calculated (Table 1A). The annual deviation from this mean for each treatment was then determined and reduced to its percentage of the average value level. The mean percentage of deviation for each treatment for the 16-year period was then calculated from these annual variations (Table 1B). Those seasons during which production for a particular treatment was less than 75% of the 16-year average for that treatment have been singled out and the extent of failure below the 75% level has been converted from dollars per acre to the basis of dollars per thousand dollars' worth of crops (Table 1C). The method of calculation is similar to that which was devised by the U. S. Dept. of Agriculture for determining the insurance costs under the crop insurance plan now in effect for wheat (3). Cost of insurance is

TABLE 1.—*Average production, fluctuation, and insurance loss cost on 10 Illinois soil experiment fields, each representing a soil group, 16-year average, 1926–1941.*

Soil treatment	Group 1 Aledo	Group 2 Hartsburg	Group 3 Kewanee	Group 4 Mt. Morris	Group 5 Carlinville	Group 6 Joliet	Group 7 Ewing	Group 10 Enfield	Group 14 Oquawka	Group 16 Elizabethtown
A. Mean Annual Production Per Acre										
O	$25.51	$22.24	$21.69	$18.70	$14.69	$16.07	$ 3.68	$ 4.82	$ 5.75	—
M	32.44	28.54	28.16	24.64	21.41	19.80	7.58	8.40	9.22	$ 8.23
ML	35.63	30.53	30.46	28.62	27.41	21.70	20.05	18.31	14.74	17.87
MLP	35.54	30.26	32.41	28.38	28.51	23.73	21.27	20.55	15.12	22.33
O	24.77	21.81	24.76	17.90	16.49	15.99	3.74	5.26	6.86	3.29
R	27.47	26.81	26.13	19.69	16.42	16.24	4.10	6.10	7.51	3.69
RL	33.22	27.23	29.53	26.39	22.25	17.02	11.24	12.79	16.00	10.96
RLP	33.60	28.26	32.01	27.90	24.51	21.57	13.18	14.67	15.94	19.00
RLPK	34.86	27.91	31.99	29.49	27.10	23.64	21.35	19.56	18.11	20.20
B. Average Deviation of Annual Crop Values from the Mean Values Given Above, %										
O	17.9	18.4	14.9	21.5	20.8	28.4	49.7	29.2	23.8	—
M	16.6	20.3	12.2	17.2	22.2	25.7	40.3	25.4	25.6	24.2
ML	13.4	16.2	12.7	16.5	18.5	22.2	22.4	19.7	23.8	22.4
MLP	14.0	16.0	11.9	13.8	19.3	18.5	19.9	16.0	23.4	19.0
O	17.8	14.1	17.9	16.1	23.3	27.8	48.8	24.2	30.7	33.7
R	16.6	13.5	18.9	16.3	25.7	28.4	46.0	21.2	30.2	40.9
RL	14.4	11.2	18.3	13.2	17.5	20.1	24.0	18.0	26.0	15.6
RLP	14.7	10.2	16.2	14.0	17.9	14.2	23.1	18.4	29.5	17.3
RLPK	14.2	10.5	16.2	13.6	16.9	15.0	16.7	12.7	24.3	17.4
C. Loss Cost per $1,000 of 75% Coverage Insurance*										
O	$34.50	$16.19	$23.97	$32.10	$30.85	$67.22	$184.78	$60.94	$36.52	—
M	30.00	31.78	21.31	23.27	20.55	64.65	121.27	52.38	45.55	$40.52
ML	23.95	11.79	18.83	24.22	7.30	53.44	30.59	36.42	48.17	31.34
MLP	25.13	10.13	20.57	22.08	11.69	50.56	18.18	20.77	46.30	25.07
O	35.52	20.78	26.92	23.84	29.91	78.40	157.14	45.69	53.94	85.02
R	23.79	3.98	8.67	11.56	40.62	58.05	155.84	48.03	59.92	115.52
RL	22.88	0.49	14.90	21.22	20.37	50.90	42.70	30.24	61.67	23.11
RLP	21.03	2.36	20.41	22.94	9.79	45.74	39.43	19.09	71.91	11.23
RLPK	22.95	2.39	30.01	23.06	1.97	43.43	13.12	16.36	59.65	19.80

*Based on actual loss experience below the 75% level during 16 years.

determined on the basis of the actual loss record of previous seasons and is termed "loss cost"; that is, an actual measure of the average income reduction below the 75% level. This calculation applied to the long-continued plots on the Illinois experiment fields gives an indication of the relative risks involved in farming different soils, on the assumption that market prices are constant.

Results including the annual deviation of each plot from its production level are given for three selected fields representing a wide range of soil conditions (Tables 2, 3, and 4). The average fluctuations in income for the various soil treatments on these three fields are shown graphically in Fig. 1 and indicate wide differences in the stability of production under the conditions represented. The average loss costs of 75% coverage insurance based on the experience of the 16-year period for the selected fields are shown in Fig. 2. They provide a direct measure of the frequency and extent of crop failure below the 75% level and indicate that both soil and soil treatment are important factors. Data from any given plot might be thought of as the

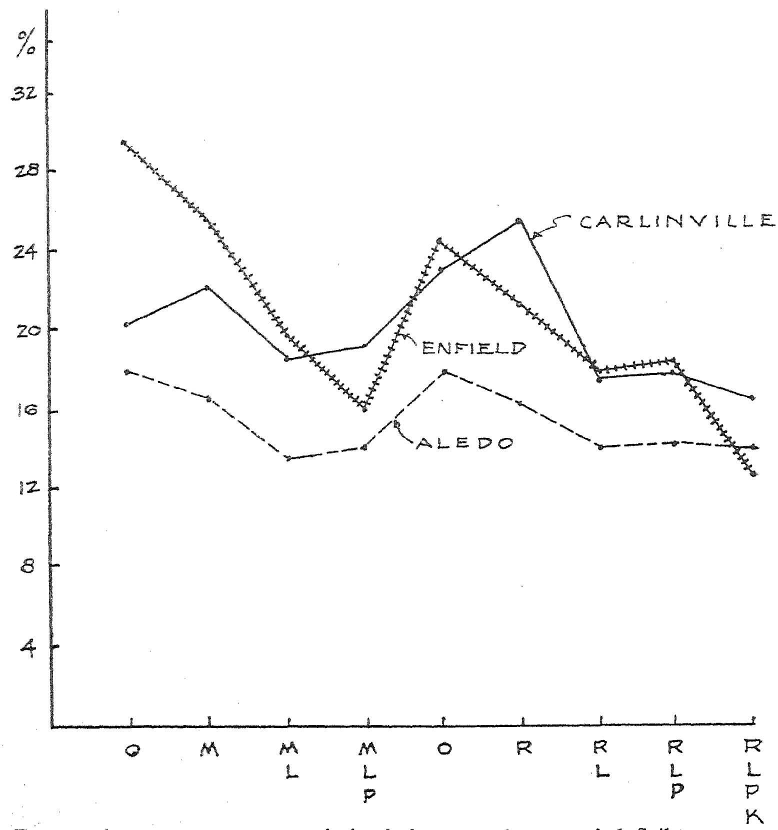

FIG. 1.—Average percentage variation in income, 16-year period. Soil treatments indicated at bottom of graph.

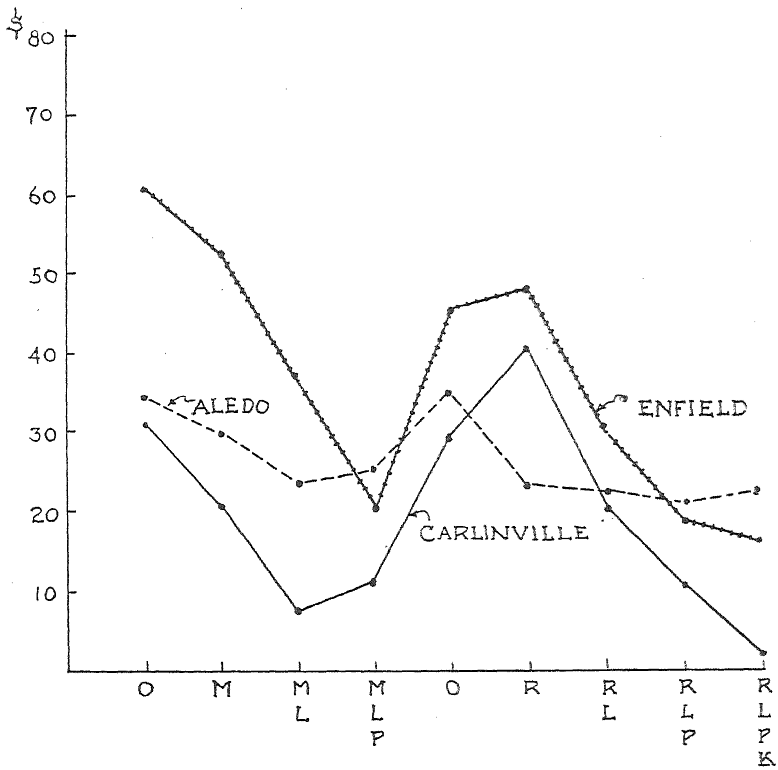

FIG. 2.—Average loss cost per $1,000 of 75% coverage insurance, 16-year period. Soil treatments indicated at bottom of graph.

basis for determining the risk involved in producing crops on that particular soil as affected by the treatment on that particular plot.

DISCUSSION OF RESULTS

The productive level was high on the dark-colored soils. At Aledo in Mercer County the average annual value of all crops grown on untreated land was more than $25 per acre. Soil treatments raised this to a gross return of more than $35 per acre annually. Variation from the average productive level was relatively low, even on the untreated land at Aledo, and was consistently reduced by soil treatment.

The droughts of 1934 and 1936 greatly reduced production in the central and northern parts of the state. Soil treatment practices were rather ineffective in preventing losses from this hazard. At Kewanee in 1934 production was low on all plots with the untreated land producing only 49% of its average level while production on the RLPK plot fell to 40% of its 16-year average. The 1934 season was the only one at Kewanee during which production fell below the 75% level, but during that season such losses occurred on all plots on that

TABLE 2.—*Results at Aledo in Mercer County on very dark, moderately heavy soil with moderately permeable subsoil.*

Soil treatment	Average acres values for 16 years	Average deviation %	Frequency of deviations within the percentage ranges indicated					Frequency of minus deviations exceeding 25%	Loss cost of 75% coverage insurance per $1,000
			0–15	15–30	30–45	45–60	60–		
O......	$25.51	17.9	11	1	3	1	..	2	$34.50
M.....	32.44	16.6	10	3	2	1	..	2	30.00
ML....	35.63	13.4	11	3	1	1	..	2	23.95
MLP...	35.54	14.0	11	3	1	1	..	2	25.13
O......	24.77	17.8	10	3	2	1	..	2	35.52
R......	27.47	16.6	9	4	2	1	..	1	23.79
RL.....	33.22	14.4	11	4	..	1	..	1	22.88
RLP...	33.60	14.7	10	4	1	1	..	1	21.03
RLPK .	34.86	14.2	12	3	..	1	..	2	22.95

TABLE 3.—*Results at Carlinville in Macoupin County on moderately dark soil with grayish cast, slowly permeable subsoil.*

Soil treatment	Average acre values for 16 years	Average deviation %	Frequency of deviations within the percentage ranges indicated					Frequency of minus deviations exceeding 25%	Loss cost of 75% coverage insurance per $1,000
			0–15	15–30	30–45	45–60	60–		
O......	$14.69	20.8	9	1	5	1	..	3	$30.85
M.....	21.41	22.2	6	5	4	1	..	3	20.55
ML....	27.41	18.5	8	4	4	..	..	2	7.30
MLP...	28.51	19.3	5	7	4	..	..	1	11.69
O......	16.49	23.3	6	5	3	1	1	3	29.91
R......	16.42	25.7	4	8	2	1	1	3	40.62
RL.....	22.25	17.5	8	3	5	—	..	2	20.37
RLP...	24.51	17.9	7	5	4	..	..	2	9.79
RLPK .	27.10	16.9	9	6	1	..	..	2	1.97

TABLE 4.—*Results at Enfield in White County on yellowish-gray, strongly leached soil with slowly permeable subsoil.*

Soil treatment	Average acre values for 16 years	Average deviation %	Frequency of deviations within the percentage ranges indicated					Frequency of minus deviations exceeding 25%	Loss cost of 75% coverage insurance per $1,000
			0–15	15–30	30–45	45–60	60–		
O......	$ 4.82	29.2	5	3	4	3	1	5	$60.94
M.....	8.40	25.4	5	6	2	3	..	5	52.38
ML....	18.31	19.7	7	3	3	1	..	3	36.42
MLP...	20.55	16.0	9	4	3	..	..	2	20.77
O......	5.26	24.2	5	6	4	1	..	3	45.69
R......	6.10	21.2	8	2	3	3	..	3	48.03
RL.....	12.79	18.0	9	2	4	1	..	2	30.24
RLP...	14.67	18.4	7	6	3	..	..	3	19.09
RLPK .	19.56	12.7	10	5	1	—	..	1	16.36

field. Conditions at Joliet were even more extreme in 1934. Production on all plots averaged less than 20% of normal with a maximum of 23% on the RLPK plot. Losses during other years at Joliet and at most of the other fields were usually reduced by the soil treatments which raised the productive level.

On the light-colored soils the percentage of deviation and the loss cost of insurance were greatly reduced by soil treatment practices. At Enfield in White County the average variation of the untreated plots was 26.7%, while that of the MLP plot was 16% and of the RLPK plot 12.7%. Insurance loss costs per $1,000 for 75% coverage were reduced from $53.31 on the untreated plots to $20.77 with MLP treatment and to $16.36 with RLPK. Results at Ewing in Franklin County were similar to those at Enfield, although on the untreated soil at Ewing deviation was almost twice that at Enfield with corresponding increase in loss cost.

The yellow hilly land represented by the experiment field at Elizabethtown in Hardin County responded well to the use of limestone and phosphate, but yield levels remained relatively low as compared to those of the dark-colored soils. However, the most effective soil treatment (RLPK) showed an average deviation of only 17.4% and a loss cost of only $19.80 per $1,000.

Production on the sandy soil at Oquawka in Henderson County was approximately trebled by soil treatment, but the risk of farming was not greatly reduced. Yield fluctuation and insurance loss costs remained relatively high regardless of treatment.

CONCLUSIONS

1. Fertile soils, under Illinois conditions, produce high average yields of rotated crops with relatively few failures.

2. Production is irregular on untreated land having low yielding ability, but on most soils it can be greatly increased and stabilized by appropriate soil treatment. Stability of production on sandy land is not greatly enhanced by soil treatment.

3. Occasionally, production may be low, even on the most fertile soils and under the best farming methods. This was the case in some parts of Illinois during the extreme droughts of 1934 and 1936.

4. Good farming methods are rewarded by high crop yields and at the same time tend to assure stable production from year to year.

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LENGTH OF DORMANCY IN CEREAL CROPS AND ITS RELATIONSHIP TO AFTER-HARVEST SPROUTING[1]

S. C. CHANG[2]

IN the central part of China, especially the Yangtze Valley region, where the prolonged, damp weather during June and July is especially conducive to the sprouting of grain either in stacks or during storage, yearly losses are great. The common farm practice in that part of China is to grow winter wheat or winter barley and rice the same year on the same land, the rice being transplanted after the wheat or barley is harvested. The harvested grain crops must be placed in stacks for 2 to 4 weeks before threshing. Since the economic conditions of farmers do not permit proper storage, the selection of a variety resistant to sprouting during June and July seems to offer a practical solution that may make possible the prevention of such losses. This study was outlined to obtain information on the variability among grain varieties in their resistance to after-harvest sprouting and the relationship of the latter to dormancy.

LITERATURE REVIEW

In his first paper on the study of the resistance of wheat varieties to sprouting in the stook and windrow, Harrington (2)[3] reported the following results: In the 1927 experiments the order of resistance to sprouting, from high to low, was Marquis 70, Kitchener, Red Fife, Red Bobs, Reward, Renfrew, Pelissier (durum), Mindum (durum), Early Red Fife, Kubanka (durum), Quality, Ruby, and Garnet. In 1931 the order was Marquis, Reward, Ceres, and Garnet.

Recently, Harrington and Knowles (4) reported the average extent of sprouting of several varieties from seven tests as follows: Apex 1789, 3.9%; Thatcher, 6.5%; Renown, 8.4%; Marquis, 11.0%; Reward, 34.0%; Reliance, 47.8%; Ceres, 57.9%; and Garnet, 78.8%. Some hybrid lines gave lower percentages of sprouting than the better parent.

Harrington and Knowles (3) also made a comparative study on dormancy of a number of varieties of both wheat and barley. The durum varieties possessed no 30-day dormancy at maturity but had a high degree of 2-day dormancy 84 days after maturity. Several vulgare varieties showed a large degree of 30-day dormancy at maturity but only a part held their 2-day dormancy for 52 days. In the test with barley varieties Trebi had the longest dormancy.

Deming and Robertson (1) studied the dormancy of 7 varieties of wheat, 13 of barley, and 3 of oats. The wheat varieties ranged from Marquis, with considerable

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[1]From a thesis submitted to the University of Minnesota in partial fulfillment of the requirements for the degree of doctor of philosophy. This paper represents but one phase of the thesis. An additional paper is being published separately. Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 1956 of the Journal Series, Minnesota Agricultural Experiment Station. Received for publication January 16, 1943.

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[3]Figures in parenthesis refer to "Literature Cited", p. 490.

dormancy for the first 10 days, to Kubanka, Kanred, and Federation with no dormancy. The barley varieties showed a range from Manchuria with no dormancy to Trebi with a dormant period of about 20 days. Two oat varieties which germinated immediately after harvest had been observed to sprout greatly in the shock under unfavorable conditions. A third variety showed a dormancy of 27 days and resisted sprouting in the shock.

Scholz (7) conducted a test on the after-ripening period of 143 varieties of bread wheat and 6 durum varieties. The durum varieties had a longer after-ripening period than the bread wheats. The after-ripening period was not found to be related to spring or winter habit or to earliness of ripening; neither was it associated with the moisture content of the grain.

Larson, Harvey, and Larson (6) conducted very extensive tests over a period of 3 years on the rest period of common varieties of wheat, oats, barley, and rye. Seeds were collected at three stages of ripeness, *viz.*, soft dough, hard dough, and ripe. The rest periods were found to be longest in immature seeds. Lowering the storage temperature generally increased the length of rest period. The varieties used in the test showed a wide range in their length of rest period. Winter wheat had, in general, a shorter rest period than spring wheat.

MATERIALS AND METHODS

In the summer of 1938, six small bundles, about 6 inches in circumference, and one large bundle, about the size of a grain binder bundle, were harvested from each of the varieties of spring and winter wheat, oats, and barley in the 1/40-acre varietal plots at University Farm, St. Paul, Minn. All bundles were left in the field to be exposed to the weather. One small bundle was taken from each variety every 10 days, starting about 2 weeks after harvest. From each of the small bundles 10 heads were selected at random and 100 kernels were threshed from the 10 heads to determine the sprouting percentage. On September 20, the last day of the 1938 experiments, 18 heads were selected at random from each of the large bundles and 300 kernels were used to determine the sprouting percentage.

In the 26 days following harvest, i.e., from July 20 to August 15, the occurrence of two light rains and two showers seemed to be insufficient to cause the sprouting of grain in the bundles and water was sprayed on the bundles on August 15, 19, and 24.

Only four or five varieties of each crop, representing various degrees of resistance to sprouting, were continued in the 1939 test. Two binder bundles were harvested from each of the selected varieties in the 1/40-acre plots at University Farm. These were left in the field. Water was sprayed on the bundles about once every 7 days. The sprouting tests were commenced about 1 month after harvest and were continued at intervals of 9 days for a period of 18 days. Since the bundles were large, two samples were taken from each bundle; one from the surface portion and the other from the middle portion. Sprouting percentage was determined separately on the two samples.

Including the same materials as those used for the sprouting studies, germination tests in the 1938 experiments were made at room temperatures using blotters. The moisture was kept as uniform as possible. One hundred unsprouted seeds were selected for each test from the same 10 heads which were used for determining the sprouting percentage. The 1938 experiment was not planned at the beginning to include the germination study. Hence, the first germination test was not started until 10 to 20 days after harvest. Further tests were made after this at intervals of 10 days. Germination counts were made every day for 10 days.

In the 1939 experiments, the same varieties were used for germination trials as those used for sprouting studies. Samples were harvested on the day the varieties matured. The germination test was started on the same day in an electrically controlled germinator at about 30° C. Seeds were stored at room temperature. Further tests were continued at intervals of 10 days. Germination counts were made on the third, sixth, and tenth day of the test. Duplicate samples of 100 seeds each were used for testing each variety.

RESULTS

VARIETAL DIFFERENCES IN DORMANCY

In Table 1 is presented the length of the dormancy period of the spring wheat varieties included in the 1938 and 1939 experiments. Varieties germinating less than 50% 10 days after starting the test were considered as in a dormancy period. As the first test in the 1938 experiment was not started until 2 to 3 weeks after maturity and as some varieties had already completed their dormancy period in the first test, the period between the date of maturity and the date on which the first test was started can be given here only as the maximum value of the length of the dormancy.

An examination of the numerical values listed in the table reveals several facts. Wide varietal differences were shown. The length of the dormancy period varied from 12 or less than 12 days for Mindum to 38 days for Progress in the 1938 experiment. In the 1939 experiment, it varied from Kubanka which did not show a rest period to Hope with a rest period of 50 days. Mindum germinated 46%, early in the first test, but the germination percentage did not increase to more than 50% until the fifth test. Hence, a range of 0 to 40 days was assigned to Mindum as the length of its dormancy period.

The winter wheat varieties showed an equal range of dormancy, indicating no relationship between the length of dormancy and spring or winter habit. The same was true of the barley and oat varieties tested, indicating that the taxonomically related plants may also be physiologically related.

The dormancy periods in the 1939 experiment were longer than in 1938. This was found to be true in all cases, except certain varieties in the 1938 experiments which had already completed their dormancy when the first test was started 2 to 3 weeks after maturity and thus no exact dormancy period could be determined. If the experimental conditions in both years are examined, it is not a difficult task to find a reasonable explanation. Thornton (8) recently reported that potatoes stored under moist conditions will sprout earlier than potatoes stored under a dry condition. The seeds used for germination tests in 1938 were taken from the crop bundles left in the field. The bundles were subjected to several showers. In addition, water sprays were applied to these bundles three times in the latter part of August. The seeds must have been in a more moist condition than the seeds used in the 1939 experiment which were stored in a room. The shortening of the dormancy period in 1938 can most probably be attributed to the moist seeds.

In his study with Algerian oats, Hyde (5) found that the high temperature during the period of exposure inhibited germination and induced a deeper state of rest. The 1938 experiments were made at room temperature which seldom reached 30° C during the summer time. The 1939 experiments were carried on most of the time at an average temperature of 30° C; frequently the temperatures were above 30° C. The high temperature in the 1939 experiments may thus. in part at least, account for the lengthening of the dormancy period.

TABLE 1.—*Comparison of varieties of spring wheat for length of dormancy period in 1938 and 1939.*

Variety	1938			1939		
	Date of maturity	Date dormancy completed*	Length of dormancy period, days	Date of maturity	Date dormancy completed	Length of dormancy period, days
Mindum	July 27	Aug. 8	12 or <12	July 30	Sept. 9	0–40
Kubanka	July 26	Aug. 8	13 or <13	July 27	July 27	0
Ceres	July 24	Aug. 8	15 or <15	July 24	Aug. 23	30
Nordhougen	July 22	Aug. 8	17 or <17	—	—	—
Reward	July 19	Aug. 8	20 or <20	—	—	—
Pilot	July 25	Aug. 18	24	—	—	—
Marquis	July 24	Aug. 18	25	—	—	—
Rival	July 23	Aug. 18	26	—	—	—
Vesta	July 22	Aug. 18	27	—	—	—
Thatcher	July 21	Aug. 18	28	July 24	Sept. 2	40
Renown	July 21	Aug. 18	28	—	—	—
H44×Reward, R.L. 1097	July 20	Aug. 18	29	—	—	—
Hope	July 20	Aug. 18	29	July 24	Sept. 12	50
Bluestem	July 26	Aug. 28	33	July 27	Sept. 5	40
Apex	July 25	Aug. 28	34	—	—	—
Komar	July 24	Aug. 28	35	—	—	—
Progress	July 21	Aug. 28	38	—	—	—

*Date of initiating the test which gave more than 50% germination within 10 days after start of trial.

Mindum gave more than 90% germination in all but one test in the 1938 experiment. Not a single test in 1939, however, gave a germination percentage over 90 and the germination did not reach 50% until the fifth test. The same two factors, moisture and temperature, which have been suggested to operate in causing the shortening and lengthening of the rest period are suggested here to account for the discrepancy of results obtained. A similar discrepancy, in a lesser degree, was obtained with Kubanka, another durum variety. This can be explained in the same manner as that used to explain the case of Mindum.

VARIETAL DIFFERENCES IN RESISTANCE TO AFTER-HARVEST SPROUTING

In Table 2 are recorded the data on percentage of after-harvest sprouting in spring wheat in the 1938 experiments. All varieties except Mindum, Kubanka, Apex, and Bluestem began to sprout

TABLE 2.—*Sprouting percentage of spring wheat varieties, 1938.*

Variety	Date of harvest	Third test, Aug. 27*	Fourth test, Sept. 6	Fifth test, Sept. 16	Sixth test, Sept. 20
Ceres	July 24	35	41	80	79
Nordhougen	July 22	34	38	78	82
Vesta	July 22	22	34	77	72
Reward	July 19	26	39	70	65
Rival	July 23	20	38	68	69
Pilot	July 25	23	24	73	62
Renown	July 21	15	35	58	68
H44×Reward R. L. 1097	July 20	18	29	60	65
Thatcher	July 21	15	24	64	68
Komar	July 24	7	28	67	63
Hope	July 25	10	32	62	59
Marquis	July 24	13	26	66	57
Apex	July 25	0	24	64	60
Bluestem	July 26	0	29	59	54
Progress	July 21	2	34	46	53
Kubanka	July 26	0	20	52	59
Mindum	July 27	0	0	47	60

*No sprouting was found at the time of the first or second tests, August 7 and 17, respectively.

August 27, 4 to 6 weeks after maturity. A close examination of the results obtained in the four tests made on August 27 and September 6, 16, and 20 reveals that greater varietal differences were obtained in the third and fourth tests than in the fifth and sixth tests. Nevertheless, the rank of each variety on the basis of sprouting percentage agrees fairly well in the four tests. Ceres and Nordhougen appeared most susceptible to sprouting as both germinated more rapidly than the other varieties. Mindum, Kubanka, Progress, Bluestem, and Apex showed relatively more resistance to sprouting. The remaining varieties fell between the two groups. In the 1939 experiments among the six varieties studied, Ceres was most susceptible to sprouting, followed by Kubanka, Thatcher, and Hope. Bluestem and Mindum were comparatively resistant to sprouting. Less marked varietal differences were obtained in the third test than in the second test of the samples taken from the middle portion of the bundle. The results of the 1939 trials are given in Table 3.

TABLE 3.—*Sprouting percentage of spring wheat varieties, 1939.*

Variety	Date of harvest	First test, Aug. 29	Second test, Sept. 7	Third test, Sept. 16
Ceres	July 24	43	52	85
Thatcher	July 24	7	34	73
Hope	July 24	4	33	79
Bluestem	July 27	2	17	78
Kubanka	July 27	7	32	79
Mindum	July 30	0	15	45

Remarkable varietal differences in sprouting percentage were observed also among the winter wheat varieties in both the 1938 and 1939 experiments. In the 1938 experiments (Table 4) all varieties failed to sprout (except 2616, with 1%) until the third test and greater varietal differences were also obtained in the third and the fourth test than in the fifth and the sixth tests. In the 1939 experiment the winter wheat samples taken from both the surface and the middle portion of the bundles exhibited a higher sprouting percentage than the corresponding samples of the spring wheat varieties. More marked varietal differences were shown in the second test than in the third test of the samples taken from the middle portion of the bundles.

TABLE 4.—*Sprouting percentage of winter wheat varieties, 1938.*

Variety	Date of harvest	Second test, Aug. 15*	Third test, Aug. 25	Fourth test, Sept. 4	Fifth test, Sept. 15	Sixth test, Sept. 20
Minturki × Marquis 2616	July 20	1	37	19	72	84
Minturki	July 20	0	31	75	72	86
Minard	July 22	0	8	6	36	71
Minhardi	July 20	0	0	11	28	49

*No sprouting at time of first test, August 5.

None of the barley varieties, Peatland, Oderbrucker, Minsturdi, Manchuria, O. A. C. 21, Velvet, Glabron, Ioglos, Wisconsin 38, Trebi, and Odessa, germinated until the fifth trial on September 11 following harvest dates ranging from July 16 to July 20, 1938. The response of each variety was similar and no differences could be detected. The 1939 results likewise demonstrated the similarity of reaction as shown in 1938.

The oat varieties studied included Gopher, Vanguard, Victory, Rusota, Nakota, Anthony, Iogold, and Minrus. As with the barley, none germinated until the fifth trial on September 14, following harvest July 21 to July 25. All varieties responded in a similar manner. Results in 1939 were similar to those secured in 1938.

In the 1939 trials samples of both the barley and the oat varieties taken from the surface portion of the bundles failed to germinate well throughout the trials and no evident varietal differences were obtained with the samples collected from the middle portion of the bundles.

RELATIONSHIP BETWEEN DORMANCY AND RESISTANCE TO AFTER-HARVEST SPROUTING

Marked varietal differences were obtained in both the length of the dormancy period and the resistance to after-harvest sprouting. If both the length of dormancy and the sprouting percentage of spring wheat varieties were examined at the same time, with the exception of two durum varieties, a negative relationship was found between length of dormancy and sprouting percentage. That is, the longer the dormancy period a variety possesses the lower its sprouting

percentage will be. Generally, such relationship held true also in winter wheat, barley, and oats.

No relationship between the length of the dormancy period and sprouting percentage was found in the two durum varieties, Mindum and Kubanka. Both varieties showed more than 40 to 50% germination in the first test of both the 1938 and 1939 experiments, while the hard red spring wheat varieties did not reach this level until the second test or later than that. Nevertheless, Mindum was most resistant to sprouting in both years and Kubanka was as resistant as Mindum in 1938 and moderately resistant in 1939. The resistance of the two durum varieties to after-harvest sprouting may be attributed primarily to slow germination. Slow germination of two durum varieties when compared with the hard red spring wheat varieties in the 1938 experiment becomes more apparent if the germination percentage of the first three days after establishing each test are studied (Table 5).

TABLE 5.—*Comparison of germination percentages of spring wheat varieties in first three days after initiating the third, fourth, and fifth tests in 1938.*

Variety	Germination percentage after third test started for indicated number of days			Germination percentage after fourth test started for indicated number of days			Germination percentage after fifth test started for indicated number of days		
	1	2	3	1	2	3	1	2	3
Mindum	0	26	83	0	5	54	0	20	53
Kubanka	0	50	77	0	4	39	1	24	42
Reward	18	94	97	13	55	69	1	93	95
Nordhougen	18	72	77	0	38	74	25	96	96
Ceres	54	96	98	0	79	85	16	96	97
Marquis	20	76	78	11	61	69	22	77	82
Hope	23	83	92	5	43	67	5	81	85
Progress	3	30	46	2	79	93	3	92	93
Bluestem	3	51	59	1	55	71	1	84	87

No marked varietal differences in resistance to sprouting were obtained in barley and oats in the 1938 experiments; hence no relationship could be determined. This has been explained as probably due to insufficiency of moisture for sprouting until the dormancy period in all varieties was completed.

The results in the present paper indicate that the differences in sprouting results were mainly due to differences in dormancy and, to some extent, may have been the result of differences in rapidity of germination.

Naturally, the sprouting results depend to a great extent on the moisture conditions during the one-month period following harvest. Only the presence of sufficient moisture before the completion of dormancy in all varieties will bring about the marked varietal differences. Some varieties showed a rest period of more than 30 days. These should be satisfactory for one month in regions where moist weather during the period is very conducive to sprouting and farmers place the harvested crops in stacks.

It is suggested that in a region where after-harvest sprouting is a problem, a germination test be included in the breeding program for a period of two months following harvest. Readings should be made every 20 or 30 days to determine varietal differences. Varieties possessing a dormancy period of more than 30 days probably will be valuable in sections where field sprouting is likely to occur.

SUMMARY

1. In 1938 and 1939 a comparative study was made of the dormancy period and after-harvest sprouting of a group of varieties of spring and winter wheat, barley, and oats grown in the 1/40-acre varietal plots at University Farm, St. Paul, Minn.

2. Marked varietal differences were obtained in both the length of the dormancy period and the resistance to after-harvest sprouting in spring and winter wheat. Less consistent differences were obtained in tests of varieties of barley and oats.

3. The existence of a relationship between the dormancy period and sprouting resistance was found to hold true in all cereal varieties with few exceptions.

4. Two durum varieties, Mindum and Kubanka, failed to show the same relationship between dormancy and sprouting resistance as other grain varieties, indicating that not the dormancy period but the germination rate and possibly other factors, such as the prevention by glumes of water penetration into the seed, determines the sprouting resistance.

5. Barley and oat varieties were found to be more resistant to after-harvest sprouting than spring and winter wheat varieties, probably because of their hull covering.

6. In 1939 winter wheat varieties gave a much higher sprouting percentage than varieties of other crops. This is not considered as a manifestation of their susceptibility to sprouting but because they matured 10 days or more earlier than varieties of other crops.

7. It is concluded that the differences in sprouting resistance are in most cases due to differences in dormancy period and in some cases they may be due to differences in rapidity of germination. Possession of hull, presence of awn, and epidermal characters of glume may play a role in resistance to after-harvest sprouting.

8. Only the presence of sufficient moisture before the completion of the rest period in all varieties will bring about the marked varietal differences. The longest dormancy period was found in the present study to be 50 days. In regions where the prolonged, damp weather lasts for one month following the crop harvest and where farmers have to put their harvested crops into stacks during this period, it may be highly desirable that the recommended variety for distribution should possess a considerable length of dormancy. Without doubt it would be much more desirable for the breeder to avoid the distribution of a variety possessing no dormancy period in a region where after-harvest sprouting has been found to be a problem.

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CORRELATION OF COMBED STAPLE LENGTH ON THE COTTONSEED WITH COMMERCIAL STAPLE LENGTH IN AMERICAN UPLAND COTTON[1]

JERRY H. MOORE[2]

LENGTH of fiber is an important factor in determining the market value of different cottons. In the United States premiums are paid for the longer cottons and a discount is made where the length of staple is below 15/16 inch. Consequently, breeders and other investigators engaged in cotton improvement work are interested in fiber length and its measurement.

Cotton fiber length is usually measured or estimated by the commercial staple method where the classer measures or estimates one or more "pulls" from a sample of lint. This method is used exclusively on the markets. The distribution of fiber length and the mean length in lint cotton or in seed cotton can also be determined by using either optical equipment or mechanical sorters. The combed staple length on the cottonseed is generally used by breeders in testing the length of fiber from cotton strains, and usually the fibers are combed out (with a small hand comb) at right angles to the long axis of the seed. Measurement of the combed staple length is made on a black velvet pad (Fig. 1). Commercial staple length can be determined only by professional classers or by cotton breeders skilled in estimating it. The relationship of results from these two methods should be known.

The purpose of this paper is to show the association of combed staple length on the cottonseed with commercial staple length in American upland cotton, *Gossypium hirsutum* L.

MATERIALS AND METHODS

The material which came from work[3] previously reported was obtained from cotton grown by farmers. Four farm areas were included in 1931 and 1932 (Table 1). The eight areas in different parts of North Carolina were assumed to provide representative data pertaining to the varieties and kind of cotton grown in the state; pure, mixed, and run-down seed from a number of different varieties were grown on varying soil types.

At the first picking 20 locks of cotton were picked from 20 plants on each farm of each area and this sample was put into a paper bag and labeled with the grower's name and address. The history of the planting seed used on the farm was recorded.

All measurements were made in the fiber laboratory under constant atmospheric conditions, 70° F and 65% relative humidity. Each lock in the sample was separated in two halves, thus making two similar samples. One of these samples was ginned on a roller gin and the other was used to make combings of the staple

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[2]Associate in Agronomy (Cotton Technology).

[3]MOORE, J. H. Relation of the quality of cotton planting seed to length of staple. N. C. Agr. Exp. Sta. Bul. 296. 1934.

on the seed. The combed staple length (Fig. 1) was measured from the raphe outward to the nearest 1/32 inch on 20 seeds, each from near the mid-point of a lock, and the average length of the sample was computed. Five determinations made to the nearest 1/32 inch were obtained from the ginned sample to compute its average commercial staple length. The pair of mean values in each full sample was recorded. The simple correlation of combed staple length on the cottonseed with commercial staple length was then calculated by areas and also by pooling all the data.

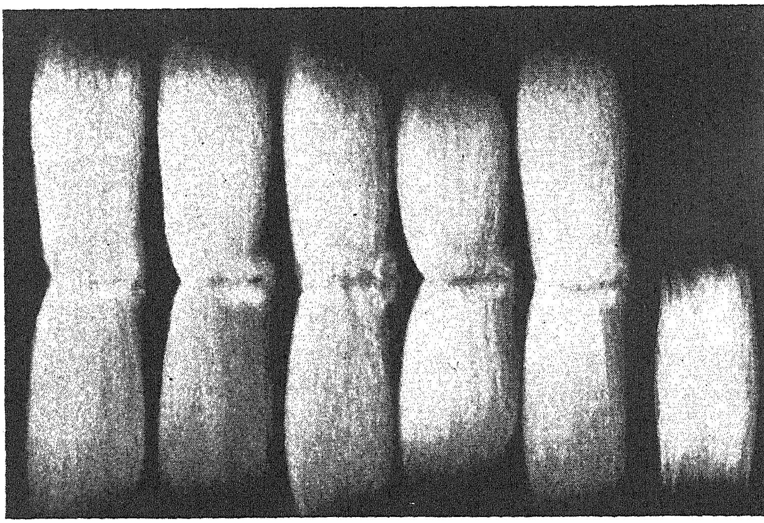

FIG. 1.—Combed staple length on seeds and commercial staple length from the same sample of cotton.

RESULTS AND DISCUSSION

The correlation of combed staple length and commercial staple length is shown by areas and for the pooled data in Table 1. All the correlation values in this table are highly significant and positive. The correlation range by areas in the 1931 crop is from .74 to .93 and in the 1932 crop from .77 to .95, while the pooled correlation for 325 samples amounts to .89. The means of combed staple length and of commercial staple length are shown by areas and for the whole experiment in Table 1. In one area the commercial staple length was longer than the combed staple length. In each of two areas the commercial staple length was shorter than the combed staple length. Comparisons in each of the five other areas indicate no significant difference. The pooled means are not different. The highest correlation, .95, is recorded for the Rockwell area, and in this area the means are identical.

Since the correlation value for the Bellwood area is only .74 and the lowest in Table 1, it seems advisable to explain, in so far as possible, why the association is low. A scatter diagram showing the dis-

TABLE 1.—*Correlation of combed staple length on the cottonseed with commercial staple length in 325 samples of American upland cotton.*

Area	No. of pairs	Value of r	Range of commercial staple length sample means in 32nd of an inch*	Average staple length in 32nd of an inch		Mean differences (combed minus commercial) and "95% range"†
				Combed	Commercial	
			1931 Crop			
Bellwood....	45	.74	26–32	29.70	29.79	−.09 ± 1.6
Cooleemee...	33	.88	27–35	31.14	31.00	.14 ± 1.1
Lumberton..	48	.93	26–36	30.50	30.95	−.45 ± 1.4‡
Winfall.....	19	.82	26–31	29.17	28.58	.59 ± 1.1‡
			1932 Crop			
Ellenboro...	60	.87	27–40	31.34	31.23	.11 ± 1.4
Plainview...	51	.77	27–35	32.19	32.32	−.13 ± 1.9
Rich Square.	31	.91	26–36	32.00	31.10	.90 ± 1.5‡
Rockwell....	38	.95	26–37	30.90	30.90	.00 ± 1.2
Pooled values	325	.89	26–40	30.99	30.93	.06 ± 1.4

*Range is given to nearest 32nd inch.
†Range is indicated by $\pm s \times t$ and includes 95% of individual differences.
‡Highly significant.

tribution of the sample means from the Bellwood area is given in Fig. 2, which indicates that the observations lie in a relatively narrow range in the direction of line AA′, with most of them located near its central portion. Each dot represents a pair of sample means. If the staple length for each member of a pair were the same, r would be 1.00 and all the dots would lie on line AA′. However, they lie at varying distances above and below this line of perfect agreement. The deviations from the line could be caused by sampling variation and errors of measurement in obtaining the sample means or by lack of perfect association between combed staple length on the seed and commercial staple length. The lines BB′ in Fig. 2 indicate the "95% range" of individual differences, obtained from $\pm s \times t$, or standard deviation $\times\, t$ at the 5% point. The difference between the Bellwood area means amounts to −.09 (combed minus commercial staple) and therefore the range lines were plotted from the value, −.09 ± 1.6. The values for the "95% range" are given in Table 1 for Bellwood and the seven other areas. The range of commercial staple length from each area is also shown in Table 1 in order to give some idea of the staple length of the samples analyzed. The range of combed staple length is not included because it is similar to that of the commercial staple length. The range of commercial staple length of the sample means is relatively narrow for the Bellwood and Plainview areas, which show the smallest values for r, .74 and .77, respectively, and the largest values for the "95% range", ± 1.6 and ± 1.9, respectively.

The value of r, .93, from the Lumberton area is relatively high, and the sample means are distributed over a wider range than are those

of the Bellwood area. The scatter diagram in Fig. 3 shows the distribution of the sample means from the Lumberton area. The range along the direction of line AA′ is wider and the "95% range" is narrower for this area than for the Bellwood area, and it seems likely that the higher correlation of the Lumberton area is associated with a wider and a more scattered distribution along the direction of line AA′. A narrower "95% range" helps to account for the higher r of the Lumberton area, but the difference is only $\pm$ 0.2 and not large enough to explain the difference in r. This means that the size of r is not necessarily associated with the accuracy of the methods used, since the correlation value is influenced by the range of staple length sample means.

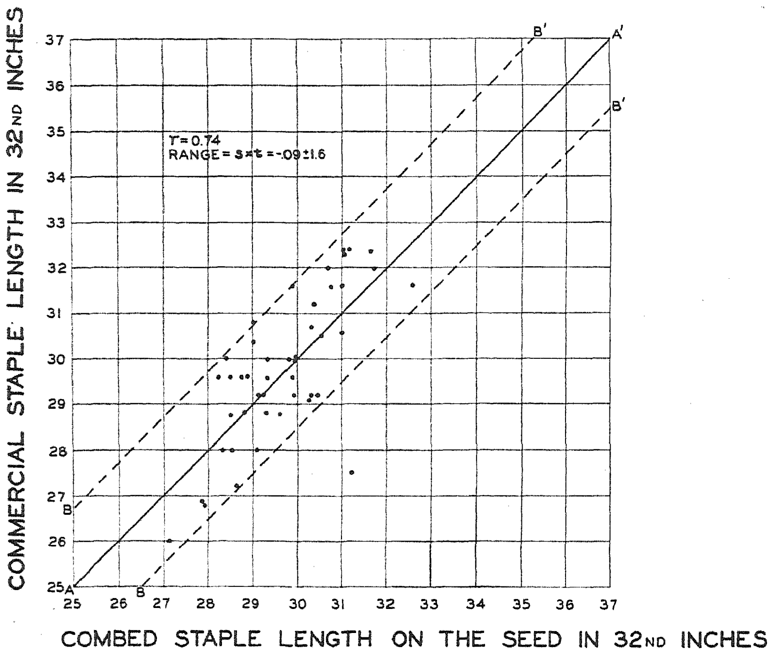

FIG. 2.—Scatter diagram showing the relation between combed staple length on the cottonseed and commercial staple length in the Bellwood area. Each dot represents a pair of sample means. The "95% range" of individual differences is indicated by lines BB′. The horizontal range for this distribution is relatively narrow.

The relationship between methods in the Bellwood area is relatively low, as previously stated, and, therefore, this area is an appropriate one for measuring the relationship within a method. The analysis within a method should be useful in explaining the lack of a high value of r between methods.

Twenty measurements of the combed staple length of each individual sample were available from the data used to calculate the relationship between combed staple length on the seed and commercial

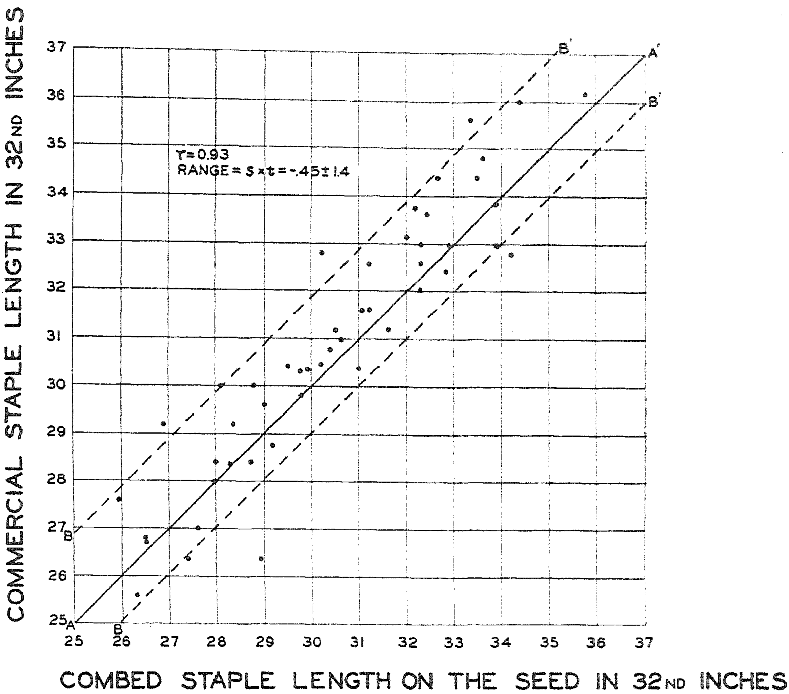

FIG. 3.—Scatter diagram showing the relation between combed staple length on the cottonseed and commercial staple length in the Lumberton area. Each dot represents a pair of sample means. The "95% range" of individual differences is indicated by lines BB′. The horizontal range for this distribution is relatively wide.

staple length. Only five measurements of commercial staple length were available from each individual sample. Because of the fact that 20 is an even number and four times greater than 5, an odd number, the relationship within a method was calculated within combed staple length, the mean of measurements from the first 10 seeds being paired with the mean of measurements from the second 10 seeds of a sample, and giving two similar samples. The relationship of the fiber length of these paired similar samples was calculated from data of the Bellwood area and the results are presented in Table 2 and Fig. 4.

TABLE 2.—*Correlation within combed staple length on the cottonseed, Bellwood area, 1931 crop.*

No. of pairs	Value of r	Range of sample means in 32nd of an inch	Average staple length in 32nd of an inch		Mean difference (Y – X) and "95% range"
			Y*	X*	
45	.66	27–33	29.56	29.81	–.25±1.6

*Y = First 10 seeds in sample; X = Second 10 seeds in sample.

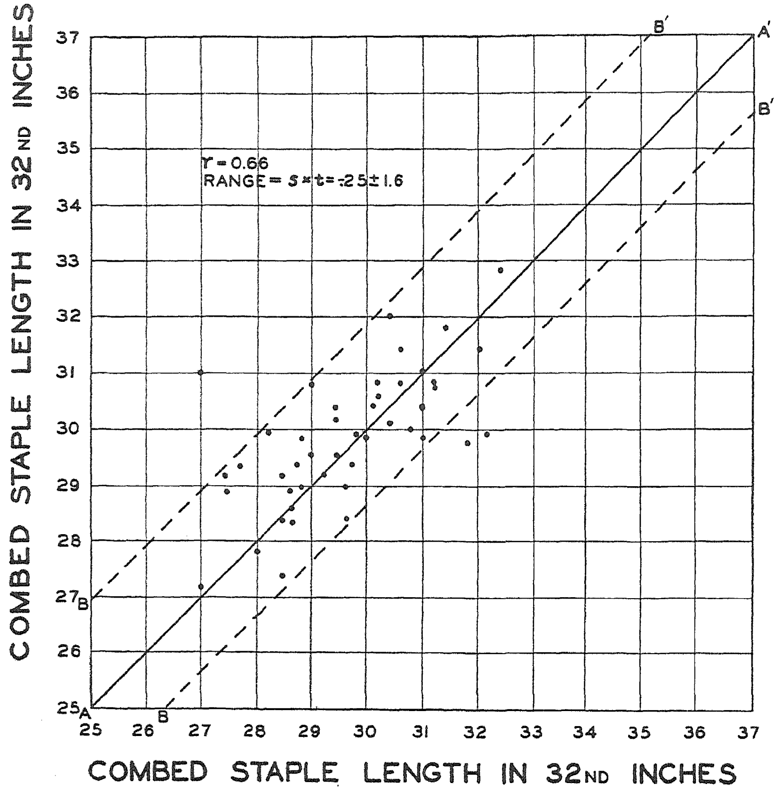

FIG. 4.—Scatter diagram showing the relation within samples of combed staple length on the cottonseed in the Bellwood area. Each dot represents a pair of sample means. The "95% range" of individual differences is indicated by lines BB′. The horizontal range for this distribution is relatively narrow.

The correlation coefficient in Table 2 amounts to .66 and is highly significant, but r, shown in Table 1, for between methods in the Bellwood area amounts to .74. The mean difference between methods is only .09, while the difference between means within a method is .25, but neither difference is significant. The tables show for the Bellwood area a value of ± 1.6 for the "95% range" of individual differences between methods and also within methods, and therefore approximately an equal degree of accuracy in sampling and measuring. The distribution of the paired sample means showing combed staple length on the seed is presented in Fig. 4 which contains a scatter diagram and the "95% range" of individual differences. A comparison of Fig. 4 with Fig. 2, which shows the distribution of sample means between methods for the Bellwood area, indicates a similar distribution, with each figure showing that a horizonal range of 4/32 inch includes nearly all of the observations, or dots. Observation of Fig. 3 points to the fact that a horizontal range of 8/32 inch (twice the

Bellwood range) includes nearly all the observations from the Lumberton area, where r is relatively high as compared to Bellwood and amounts to .93. It seems probable that the relatively low correlation for the Bellwood area is associated with the narrow horizontal range discussed above and also with sampling variation and errors of measurements. Bellwood is also probably somewhat typical of such areas as Winfall and Plainview, while Lumberton seems to be similar to the Cooleemee, Ellenboro, Rich Square, and Rockwell areas.

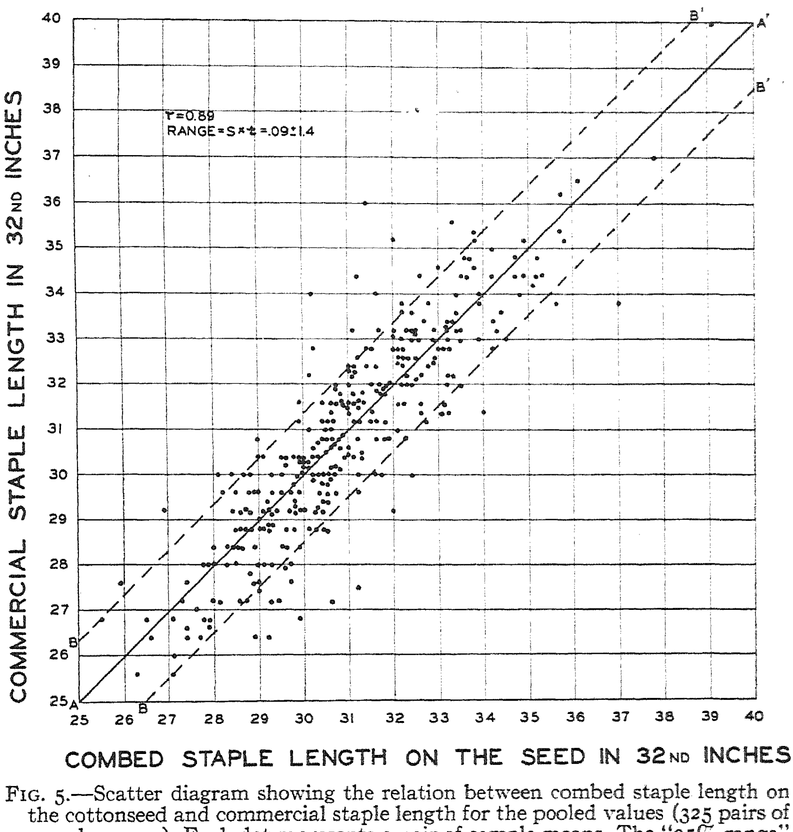

FIG. 5.—Scatter diagram showing the relation between combed staple length on the cottonseed and commercial staple length for the pooled values (325 pairs of sample means). Each dot represents a pair of sample means. The "95% range" of individual differences is indicated by lines BB'. The distribution appears to be approximately normal.

Since the correlation value for the Bellwood area is lower within a method than between methods, it appears that the low r between methods is due to variability within the sample means and the narrow range of their distribution. To obtain a higher correlation it would be necessary to make more measurements to obtain the sample means. Theoretically, the correlation within combed staple length in the Bellwood area should approach 1.00, yet it is only .66 because of sampling variation, errors of measurement, and the narrow range

of the distribution. Regardless of this narrow range in which the observations lie along the curve, r would amount to 1.00 if the paired samples were identical and an infinite number of measurements could be made to determine each sample mean.

The pooled values from 325 pairs of sample means probably give a better index of the relationship of the two methods than any particular area. The data in the scatter diagram shown in Fig. 5 indicate that the pooled observations of the experiment simulate a normal distribution. The correlation coefficient for pooled values amounts to .89 (Table 1) and there is no real difference between the pooled means. Only 13% of the 325 samples was grown from seed of pure varieties, while the remaining 87% was grown from mixed varieties which usually showed a high coefficient of variability for fiber length. Moore and Stutts[4] reported a coefficient of variability of 4.55% for the combed staple length of a pure variety and 8.06% for that of a mixed variety. Laboratory records of the 325 samples of this experiment indicate that most of them showed a coefficient of variability within a range of 7 to 10%. Considering this high variability and the limited number of measurements made to obtain each sample mean, an r value of .89 does not appear to be low. If the experiment could be repeated and the number of measurements for each sample mean doubled, it is believed that the correlation coefficient would be considerably larger.

Breeders and other investigators working with varieties more nearly homozygous for fiber length might expect a high correlation between combed staple length and commercial staple by making a relatively small number of measurements for each sample mean. The correlation coefficient obtained between the two methods depends upon the variability of the samples; errors in combing, stapling, and measuring; and the range of the distribution on the curve.

SUMMARY

Measurements made within 325 samples from representative American upland varieties of cotton, *Gossypium hirsutum* L., grown on North Carolina farms for two seasons indicate a highly significant correlation of .89 between the combed staple length on the seed and the commercial staple length and no real mean difference. This fairly close relationship points to a practical value in that either method, i.e., combed staple on seed or commercial staple length, may be used to show differences in fiber length between samples, or one method may be used to check the accuracy of the other. Since the fibers on the seed can be combed and measured by relatively inexperienced help, the fiber length should perhaps, wherever possible, be measured on the seed when a shortage of skilled help precludes the application of both methods.

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EFFECT OF IRRIGATION TREATMENTS ON STEM ROT SEVERITY, PLANT DEVELOPMENT, YIELD, AND QUALITY OF RICE[1]

E. M. CRALLEY AND C. ROY ADAIR[2]

IN a previous publication, Tullis and Cralley (7)[3] mention draining prior to maturity as a promising method for the control of stem rot of rice caused by *Leptosphaeria salvinii* Catt. These observations were limited to the variety Supreme Blue Rose. Since that time additional experiments have been conducted to determine the effect of various irrigation treatments on stem rot severity of several rice varieties and on tillering, plant height, yield, and milling quality. Jones (4) has shown that different irrigation treatments affect rice yields. Tisdale and Jenkins (6) recommended draining as a control for straighthead of rice, and Isely and Schwardt (3) recommended draining for the control of rice water weevil.

MATERIALS AND METHODS

The experiments reported herein were conducted at the Rice Branch Experiment Station, Stuttgart, Ark., on plots which up to 1933 had grown 19 crops of rice during the preceding 24-year period. In the course of the experiments, rice was grown on the plots in alternate years, one series of experiments on stem-rot-infested and the other on stem-rot-free land.

STEM-ROT-INFESTED PLOTS

In the stem-rot-infested series, the experiments were set up in a block arrangement, using triplicated or quadruplicated 1/50-acre randomized plots. In order to obtain a more critical comparison of the effects of the various irrigation treatments on disease severity, a disease index value was computed for each treatment. The method of computing this index has been explained previously (1).

The irrigation treatments were as follows: (a) Soil kept moist but not submerged during the entire growing season; (b) soil irrigated normally until the first part of August, then kept moist but not submerged for the remainder of the season; (c) soil irrigated normally until the last part of August or first part of September, then kept moist but not submerged for the remainder of the season; (d) soil irrigated normally until August 15, then kept moist but not submerged until September 1, then irrigated normally for remainder of the season; and (e) normal irrigation. Normal irrigation consisted of submerging the soil 2 to 3 inches deep for about 3 weeks when the plants were approximately 6 inches in height, permitting the land to dry for 2 weeks, then applying water to a depth of 4 to 6

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[2]Associate Plant Pathologist, Arkansas Agricultural Experiment Station, and Associate Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 506.

TABLE 1.—*Effect of irrigation treatments on the severity of stem rot and the yield of rice varieties.*

Variety	Year	Irrigation treatments										Average	
		Soil kept moist entire season		Soil kept moist after Aug. 10		Soil kept moist after Aug. 30		Alternate drainage and submergence after Aug. 15		Normal irrigation		Index	Yield
		Mean index	Mean yield	Mean index	Mean yield	Mean index	Mean yield	Mean index	Mean yield	Mean index	Mean yield		
Caloro	1933	9.5	37.5	14.0	43.5	24.0	25.5	—	—	35.5	35.0	20.8	35.4
Lady Wright	1933	10.0	42.5	22.0	45.5	20.0	28.5	—	—	34.0	43.5	21.5	40.0
Supreme Blue Rose	1933	22.0	48.0	20.5	51.5	33.0	40.0	—	—	58.5	47.5	33.5	46.8
Average		13.8	42.7	18.8	46.8	25.7	31.3	—	—	42.7	42.0	—	—
Caloro	1934	1.2	16.5	8.0	31.0	9.7	33.5	—	—	14.0	35.7	8.2	29.2
Lady Wright	1934	0.2	5.5	9.0	16.7	11.5	19.7	—	—	18.0	19.7	9.7	15.4
Supreme Blue Rose	1934	1.0	22.0	13.7	44.5	20.7	53.5	—	—	35.0	54.5	17.6	43.6
Average		0.8	14.7	10.2	30.7	14.0	35.6	—	—	22.3	36.6	—	—

Caloro	1935	—	—	39.3	30.6	13.3	33.6	—	—	26.6	35.3	26.4	33.2
Early Prolific	1935	—	—	2.0	34.6	3.6	39.0	—	—	6.3	40.0	4.0	37.9
Supreme Blue Rose	1935	—	—	13.6	38.3	13.0	38.6	—	—	22.3	39.6	16.3	38.8
Average		—	—	18.3	34.5	10.0	37.1	—	—	18.4	38.3	—	—
Caloro	1936	—	—	2.2	29.2	4.2	35.0	—	—	7.0	42.0	4.5	35.4
Early Prolific	1936	—	—	19.7	43.7	11.7	42.0	—	—	16.7	43.5	16.0	43.1
Supreme Blue Rose	1936	—	—	8.7	49.7	14.0	51.7	—	—	22.7	48.0	15.1	49.8
Average		—	—	10.2	40.9	10.0	42.9	—	—	15.5	44.5	—	—
Fortuna	1939	—	—	48.0	38.4	51.3	26.6	49.0	34.0	52.0	31.0	50.1	32.5
Supreme Blue Rose	1939	—	—	14.6	26.0	22.6	20.0	19.3	24.6	28.0	24.3	21.1	23.7
Kameji × Blue Rose	1939	—	—	33.3	31.3	43.3	30.6	35.3	34.0	41.0	41.3	38.2	34.3
Average		—	—	32.0	31.9	39.1	25.7	34.5	30.9	40.3	32.2	—	—
Fortuna	1940	—	—	63.6	33.3	49.6	34.3	40.3	38.6	47.0	41.6	50.1	37.0
Supreme Blue Rose	1940	—	—	17.3	24.3	26.3	38.0	24.0	21.3	38.0	27.3	26.4	25.2
Kameji × Blue Rose	1940	—	—	20.0	32.0	47.6	27.3	28.3	33.0	46.3	31.0	35.6	30.8
Average		—	—	33.6	29.9	41.2	29.9	30.9	31.0	43.8	33.3	—	—
Average of all varieties		7.3	28.7	20.5	35.8	23.3	33.7	32.7	30.9	30.5	37.8	—	—

inches which is held on the land until about 2 weeks prior to harvest. Thus the soil was submerged 60 to 100 days each year, the actual submergence period being dependent on such factors as time of seeding and the time of maturity of the varieties.

STEM-ROT-FREE PLOTS

The second set of experiments on stem-rot-free land included the Supreme Blue Rose variety only. The irrigation treatments used in this series were as follows: (a) Soil continuously submerged from seeding time to just prior to harvest; (b) soil continuously submerged from time of first irrigation to 2 weeks before harvest; (c) normal irrigation; (d) normal irrigation except the land was not drained until harvest; (e) normal irrigation except the land was drained a month preceding harvest and the soil kept moist; (f) normal irrigation except drained a second time about 3 weeks after the second irrigation and dried for 2 weeks and then irrigated; and (g) land kept moist from the time of first irrigation until about 2 weeks before harvest. Data were taken over a period of 4 years on the effect of irrigation treatments on tillering, plant height, yield, and milling quality. The date of seeding was approximately April 28 and of harvest October 14. Three systematically replicated nursery plots were used in 1934, 1935, and 1936. Only treatments Nos. 1, 2, 3, and 6 were used in 1937 and they were arranged in a 4 × 4 latin square. In the latin square, the plots were 49 by 46 inches. In treatments Nos. 2 to 7, the rice was sown in rows 8 inches apart and the plants were thinned to approximately 2 inches apart in the row at the time the first irrigation water was applied. In treatment No. 1 the rice was sown broadcast in the water and the plants were thinned so that each was separate. In treatment No. 1 the stand in 1937 was poor and plants removed from other plots were transplanted to them. The deviation from the mean method, as suggested by Hayes (2), was used to determine the standard deviation.

The number of culms per plant, the height of the main culm, and the number of plants per plot were recorded when the rice was harvested. All plants from a plot were cured, weighed, threshed, and the weight of the grain recorded. The milling quality was determined by the Smith shelling device (5).

RESULTS

STEM-ROT-INFESTED PLOTS

The results of the experiments conducted on stem-rot-infested soil are presented in Tables 1 and 2. The data in Table 1 show that the yields, as well as the disease indices, were uniformly low throughout the investigations. In no case did the disease indices approach 100, a condition sometimes observed in badly infested fields where 75 to 100% of the plants may lodge. Actually, the results show the effect of different irrigation treatments on the yield of rice under conditions of light stem rot infection. The analyses of the results presented in Table 1 are given in Table 2. The analysis in general shows a significant difference between varieties for both disease indices and yields. There were no significant differences between the irrigation treatments except in 1933 and 1934, and the variety × irrigation treatment interaction was significant for yields only in 1934, 1936, and 1940. A summary of the data presented in Table 3 shows that the average disease indices were always higher in rice irrigated normally. However, as indicated above, the differences were small and in most

TABLE 2.—*F values for data in Table 1.*

Year		Variety	Irrigation treatments	Varieties × irrigation treatments
1933	Indices	2.97	6.90†	0.46
	Yield	3.48	3.48	0.12
1934	Indices	6.47†	15.51†	1.41
	Yield	177.82†	74.86†	4.13†
1935	Indices	14.83†	2.67	2.61
	Yield	3.33	1.34	0.19
1936	Indices	11.49†	2.67	1.99
	Yield	26.46†	1.65	3.01*
1939	Indices	26.12†	1.41	0.17
	Yield	8.71†	1.84	0.95
1940	Indices	11.58†	2.25	2.46
	Yield	38.74†	2.21	3.18*

*Low significance.
†High significance.

instances not significant. These data also show that the small decreases in disease severity due to draining were not accompanied by increased yield. From these results it appears, therefore, that when stem-rot infection is light, early draining will not increase the yields of rice.

TABLE 3.—*Effect of irrigation treatments on the severity of stem rot and the yield of rice.*

Irrigation treatments	Period	Average	
		Indices	Yield, bu. per acre
Soil kept moist entire season	1933–34 inc.	7.3	28.7
Normal irrigation	1933–34 inc.	32.5	39.3
Soil kept moist after Aug. 10	1933–36 inc. and 1939–40 inc.	20.5	35.8
Normal irrigation	1933–36 inc. and 1939–40 inc.	30.5	37.8
Soil kept moist after about Aug. 30	1933–36 inc. and 1939–40 inc.	23.3	33.7
Normal irrigation	1933–36 inc. and 1939–40 inc.	30.5	37.8
Alternate drainage and submergence	1939–40 inc.	32.7	30.9
Normal irrigation	1939–40 inc.	42.0	32.7

STEM-ROT-FREE PLOTS

The results of series 2, grown on stem-rot-free land, are presented in Table 4. The number of plants was about the same for all plots on

TABLE 4.—*Results of irrigation treatments on tillering, plant height, yield, and milling quality of rice.*

Irrigation treatment	Year	Plant height, inches	No. of culms per plant	No. of plants per plot	Grain per panicle, grams	Grain per plot		Straw per plot, grams	Grain straw ratio	Milling quality*	
						Yield, grams	S.D. of mean, grams			Broken kernels, %	Whole kernels, %
Continuous†	1934	37.9	1.21	167	—	440	49.3	725	1.65	4.86	72.16
	1935	38.1	1.28	115	—	339	33.4	600	1.77	7.53	68.67
	1936	36.4	1.66	93	—	326	33.7	—	—	9.80	63.50
	1937‡	46.5	3.87	61	—	728	42.8	—	—	1.82	76.98
Average	1934–36	37.5	1.38	125	2.13	368	22.8	663	1.71	7.40	68.11
Continuous until 2 weeks before harvest	1934	39.9	2.03	95	—	443	49.6	790	1.78	4.51	72.72
	1935	39.0	1.84	73	—	410	40.4	695	1.70	12.03	63.63
	1936	36.9	1.38	87	—	330	34.1	—	—	9.10	64.20
	1937	42.5	2.26	82	—	497	29.2	—	—	1.90	77.10
Average	1934–36	38.6	1.75	88	2.56	394	27.0	743	1.74	8.55	66.85
	1934–37	39.6	1.88	84	2.66	420	21.5	—	—	6.88	69.39
Normal	1934	36.8	2.00	91	—	350	39.2	697	1.99	4.52	72.18
	1935	35.5	1.84	77	—	249	24.5	723	2.90	8.70	66.77
	1936	36.1	1.71	84	—	318	32.9	—	—	12.40	60.80
	1937	42.4	2.33	76	—	496	29.2	—	—	2.74	76.15
Average	1934–36	36.1	1.85	84	1.97	306	18.9	710	2.45	8.54	66.65
	1934–37	37.7	1.97	82	2.19	353	16.0	—	—	7.09	69.02

Normal with late drainage	1934	38.0	1.94	95	—	370	41.4	702	1.90	5.15	70.86
	1935	34.7	1.96	81	—	260	25.6	726	2.79	8.70	66.60
	1936	36.0	1.72	85	—	325	33.6	—	—	11.80	61.00
Average	1934–36	36.2	1.87	87	1.95	318	19.7	714	2.35	8.56	66.15
Normal with early drainage	1934	37.9	2.00	85	—	356	39.9	661	1.86	4.78	71.70
	1935	35.0	1.98	80	—	282	27.8	779	2.76	8.73	66.57
	1936	36.0	1.70	87	—	334	34.5	—	—	10.50	62.60
Average	1934–36	36.3	1.89	84	2.04	324	19.9	720	2.04	8.00	66.96
Normal, drained twice	1934	38.4	1.85	94	—	367	41.1	657	1.79	5.20	71.54
	1935	36.0	1.98	72	—	282	27.8	688	2.44	8.70	67.03
	1936	36.1	1.69	86	—	302	31.2	—	—	10.40	62.50
	1937	42.1	2.26	76	—	425	25.0	—	—	2.43	76.17
Average	1934–36	36.8	1.84	84	2.05	317	19.5	673	2.12	8.10	67.02
	1934–37	38.1	1.94	82	2.16	344	15.9	—	—	6.68	69.31
Land kept moist	1934	34.3	1.60	47	—	130	14.6	319	2.45	5.98	70.50
	1935	33.7	1.42	64	—	137	13.5	595	4.34	10.13	61.47
	1936	32.3	1.37	74	—	199	20.6	—	—	8.90	64.10
Average	1934–36	33.4	1.46	62	1.71	155	9.5	457	3.40	8.43	65.36

*The weight per bushel was determined in 1934 and 1936; the average for the two years ranged from 42.7 for treatment 5 to 43.0 for treatment 4.
†Sown in water.
‡Transplanted in 1937.

which the seeds were sown in the soil, except those kept moist throughout the growing season, and for those in which the seed was sown in the water. On submerged land, the growth of weeds and grasses is restricted, whereas, on land kept muddy but not submerged, weeds and grasses often reduce the stands of rice and also the vigor of the plants that survive. There were more plants on plots in which the seed was sown in the water than for those in which the seed was sown in the soil because the plots were not thinned to give the same number of plants.

The average height of the plants grown by the different irrigation treatments was essentially the same, except that plants were shorter on plots not submerged. Plants from seed sown in the water and plants grown on plots not submerged did not tiller as well as those receiving other irrigation treatments. The reduction in tillers for these treatments was probably due to thicker stands of rice when sown in the water and to weed and grass competition in plots not submerged.

The largest panicles were produced by plants grown on continuously submerged plots, and the smallest by plants grown on plots kept moist but not submerged. The highest average grain yield was produced on continuously submerged plots; the yields on plots kept moist but not submerged were significantly lower than those of other treatments. The difference in yield among the first six treatments was not significant. Plants grown on plots continuously submerged gave the least and those grown on moist but not submerged land the most straw in relation to grain.

The treatment that gave the highest yield also tended to produce rice of the highest quality. This relationship was not consistent, but apparently any condition that reduces plant vigor also interferes with the quality of the rice.

SUMMARY

Experiments were conducted to study the effect of irrigation treatments on the severity of stem rot, tillering, plant height, yield, and milling quality of rice.

Stem rot severity was slightly reduced by withholding water from experimental plots for certain periods prior to harvest and by alternate draining and submergence during the latter part of the growing season. The average yields, however, were somewhat higher from plots irrigated normally; that is, submerged continuously during the latter part of the growing season. The data indicate that early draining, when practiced in fields lightly infested with stem rot, does not increase the yields of rice.

Various draining treatments when compared with the normal irrigation practice failed to increase plant height, tillering, weight of panicle, or yield, nor did they improve the milling quality of the rice.

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THE VARIABILITY OF CERTAIN QUANTITATIVE CHARACTERS OF A DOUBLE CROSS HYBRID IN CORN AS RELATED TO THE METHOD OF COMBINING THE FOUR INBREDS[1]

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IT has become a common practice by many corn breeders to make single crosses within a group of inbred lines, test these in yield trials, and predict the performance of double crosses. The yield of a particular double cross is predicted from the average of four of the six possible single crosses that can be made from four inbreds, the two parental single crosses not being used in the average.

In a consideration of the prospective performance of double crosses, relative yields, disease reaction, and lodging resistance are of primary importance. In addition, uniformity of characters of a double cross is given consideration. The problem arises as to whether it is possible to predict the degree of uniformity in a double cross on the basis of a study of the characters of the inbred parents and of their single crosses. This paper presents data obtained from inbreds, single crosses, and double crosses, using four inbreds which differed widely in several characters.

REVIEW OF LITERATURE

Jenkins (7)[3] was the first to present data on methods of predicting the performance of double crosses. One of his methods was to average the performance of the four non-parental single cross combinations. This method fairly well represents the actual hybrid combination occurring, since, as Jenkins states, "In any double cross the genes of each of the four parental lines are united only with allelomorphs of the two lines which enter the double cross from the opposite parent."

Doxtator and Johnson (2) showed that significant differences in yielding ability could be found in the three double crosses from the same four lines and that these differences were predictable by the above method.

Anderson (1) also predicted yields in this manner and obtained a correlation of .90 between predicted and actual yields of 15 double crosses.

In a recent paper, Hayes, Murphy and Rinke (6) present further results of the application of this method at Minnesota.

Eckhardt and Bryan (3) measured individual plants in double crosses involving two inbreds from each of two varieties. Designating inbreds from one variety as A and B and those from another variety as Y and Z, they found that hybrids

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[3]Figures in parenthesis refer to "Literature Cited", p. 514.

of the type (A × B) (Y × Z) gave significantly lower variances for ear height and ear length than did hybrids of the type (A × Y) (B × Z). However, plant height, ear weight, and ear diameter were not significantly less variable in the (A × B) (Y × Z) double crosses. The authors reasoned that single crosses of the (A × B) or (Y × Z) type contained inbreds more alike genetically than single crosses of the (A × Y) or (B × Z) type.

In a similar manner, Eckhardt and Bryan (4) studied double crosses designated (E × E) (L × L) and (E × L) (E × L), where E indicates early inbreds and L indicates late. Hybrids of the latter type were significantly more variable in silking date, ear height, ear diameter, and ear length, while in plant height one year's data showed no difference in the two types of hybrids but the second year's data showed more variability in the (E × L) (E × L) double crosses. Here again the single crosses of the (E × E) or (L × L) type were assumed to contain inbreds more genetically alike than the (E × L) type. In the above study two out of eight hybrids involved inbreds from four varieties. The remaining six had either two or three varieties represented in their genetic composition.

MATERIALS AND METHODS

Four inbreds, A25, A71, A111, and A158 (Table 1) were selected for study on the basis that they were of diverse origin and differed widely in several different quantitative characters.

TABLE 1.—*Inbred lines, their origins, general characters, and length of time selfed prior to 1940.*

Inbred	Origin	Description of characters	No. of years selfed
A25	Purdue Yellow Dent	Late, tall, high ears, large leaf area, short ear, high row number	11
A71	Wisconsin (variety unknown)	Same as A25 except for long ear and low row number	17
A111	49 (Minn. No. 13)×9–29 (Ost. Y. D.)	Early, short, low ears, small leaf area, short ear, high row number	7
A158	43 (Minn. No. 13)×47 (Minn. No. 13)	Same as A111 except for long ear and low row number	9

In 1941 the inbreds, their six single crosses, and three double crosses were grown in three separate groups of eight randomized blocks each at Waseca, Minn. Each entry was planted in three-row plots, 33 feet in length, one plant per foot, but only 25 plants of the center row were used for individual plant measurements. Approximately 200 plants of each inbred, single cross, and double cross were measured individually for the following characters: Date of silking, date of first pollen, ear height, plant height, ear leaf area, percentage ear moisture, ear length, and row number.

Date of silking and date of first pollen were taken in days after June 30. Ear height, plant height, and ear length were measured in inches. Ear leaf area was calculated in square inches by multiplying the product of length and width by 0.75. Ear moisture was computed from gram weights of individual ears at the

normal harvesting period in the fall and after oven drying. Row numbers were counted at about one-fourth the distance from the butt to the tip of the ear.

EXPERIMENTAL RESULTS

AVERAGES FOR INBREDS, SINGLE CROSSES, AND DOUBLE CROSSES

The means for all characters of the inbreds and single crosses appear in Table 2. F values were calculated to determine whether the inbreds differed significantly in the characters studied and similar studies were made for the single crosses. The calculated value, L.S., given in the table, indicates the least significant difference between means to give odds of 19:1 that a difference as great as the L.S. value would not be obtained by chance alone. The two pairs of inbreds A25 and A71 and A111 and A158 differ widely for the first six characters listed in the table. A25 and A71 are much later, taller, and have more leaf area than either A111 or A158. The differences in ear length and row number are not so obvious, but the F values for these indicate highly significant differences. Using the levels of significance, 0.2 inch and 0.6 row, it can be determined that A71 and A158 have longer ears than the other two lines while A25 and A111 have larger numbers of rows.

It is of interest to compare the characters of the single crosses also. The cross A25 × A71 has the highest averages for the first six characters and A111 × A158 has the lowest averages for these characters. This is exactly the same relationship that is present in the inbreds themselves. A71 and A158 have the longest ears among the inbreds and when crossed give the longest eared single crosses. A25 and A111 have short ears and give the shortest eared single cross. Similarly, A71 and A158 were low in row number as was their single cross, while A25 × A111 was highest in row number.

Thus it appears that the two lines with the "high" means for any particular character gave the "high" single cross, while the two "low" lines gave the "low" single cross in each instance.

There were also significant differences between the high × low single crosses. Considering 25 × 111, 25 × 158, 71 × 111, and 71 × 158 for only the first six characters in Table 2, it can be seen that they differ to some extent but not nearly so widely as do the crosses 25 × 71 and 111 × 158.

Table 3 shows the results which indicate that there were no significant differences between the averages of the three double crosses for any of the eight characters. For certain characters the averages of the three double crosses were almost identical. For example, plant heights and ear lengths were 89.4, 89.4, and 90.2 inches and 6.8, 6.8, and 6.8 inches for double crosses A, B, and C, respectively.

VARIATION IN THE CHARACTERS OF THE DOUBLE CROSSES

Differences in variability of the three double crosses for each character were determined in the following manner. The variance (v) of a character was calculated for each plot of 25 plants. A standard

TABLE 2.—*Mean values for eight characters of the inbreds and of their six single crosses with F values and levels of significance to indicate the extent of the differences within the inbreds and within the single crosses.*

Characters	Summary of analyses of variance on means of													
	Inbreds						Single crosses							
	A25	A71	A111	A158	L.S.*	F value†	25×71	25×111	25×158	71×111	71×158	111×158	L.S.	F†
Moisture	41.5	40.4	14.5	14.1	—	—	35.2	24.1	31.2	27.7	28.6	22.0	1.3	104
Date silk	32.8	32.8	23.7	25.4	—	—	30.6	24.7	27.6	24.3	26.3	21.3	1.1	68
Date pollen	30.8	30.6	21.0	22.5	—	—	27.3	22.6	24.4	22.3	22.8	18.8	0.7	132
Ear height	22.5	26.6	10.7	14.0	—	—	44.3	31.1	34.1	36.0	37.9	25.0	1.9	113
Plant height	66.0	64.4	50.6	52.8	—	—	101.0	92.1	86.8	86.8	85.8	73.2	2.2	139
Leaf area	81.1	88.5	38.4	36.0	—	—	121.7	99.4	96.6	98.0	90.2	65.0	3.0	292
Ear length	4.9	5.2	4.5	5.8	0.2	57.6	6.8	6.2	6.8	7.0	7.4	6.8	0.3	13
Row number	17.6	13.5	15.7	13.6	0.6	179.5	17.1	19.5	16.6	16.5	14.4	15.7	0.4	144

*Least significant difference. Because of obviously wide differences in other characters only ear length and row number of the inbreds were analyzed.
†All F values in this table exceed the 1% level by a wide margin.

error (s) for this variance was computed by Fisher's formula (5) $s_v = \sqrt{\frac{2v^2}{N - 1}}$. The mean variance ($\bar{v}$) for any character consisted of the arithmetic average of the variances for all eight replications. The error ($\bar{s}$) for this mean variance ($\bar{v}$) was calculated by reducing the error of the plot variances according to the formula $\bar{s} = \frac{1}{8} \sqrt{s_1 + s_2 + s_3 \ldots . s_8}$, where s_1, s_2, etc., are the standard errors for the variances of replications 1, 2, 3, etc.

TABLE 3.—*Means of eight characters of the double crosses with F values to indicate the extent of differences between double crosses A, (25×71)×(111×158); B, (25×111)×(71×158); and C, (25×158)×(71×111).*

Character	Measure	Means of double crosses			F value*
		A	B	C	
Moisture	Per cent	27.3	26.6	27.1	0.43
Date silk	Days after June 30	23.9	24.1	23.4	0.99
Date pollen	Days after June 30	21.5	21.5	21.1	1.14
Ear height	Inches	36.8	35.6	35.4	1.99
Plant height	Inches	89.4	89.4	90.2	0.40
Ear leaf area	Square inches	94.5	92.5	93.0	0.93
Ear length	Inches	6.83	6.79	6.82	0.07
Row number	Rows	16.5	16.6	16.8	3.18

*F value of 3.74 required for significance at the 5% point.

Then the mean variances for any character were compared directly within pairs of double crosses by means of the test "t" $= \frac{\bar{x}}{\sqrt{\bar{s}_1 + \bar{s}_2}}$, where $\bar{x}$ is the difference between two mean variances and $\bar{s}_1$ and $\bar{s}_2$ are the standard errors of these variances of two hybrids.

The mean variances for all characters, their errors, and the *t* values for the 24 possible comparisons among the three double crosses appear in Table 4.

In the first column of *t* values it can be seen that double cross B was more variable than A in date of silking and ear leaf area, significance at the 1% point being established for the first character. The *t* value for plant height approaches significance and B again was most variable.

In the second column double cross A is compared with C. Only moisture and ear length variances even approach significance. Here C is in the direction of lower variability.

In the third column double crosses B and C are compared. It was expected that they would be similar in variability for six of the eight characters, while for ear length and row number B would be more uniform than C (or A). However, for ear moisture and date of silking, B is more variable than C at odds of 19:1 and 99:1, respectively. Five of the remaining six *t* values approach the 5% point in the direction of greater variability for B. Thus, the largest differences between

hybrids occur in a pair expected to be equal in variability for six characters.

Out of the 24 comparisons four were significant; two of these were in the direction expected and two were not. Eight more approached significance, one in the direction expected and seven in the opposite direction. The remaining 12 comparisons were evenly divided in their implications.

TABLE 4.—*The mean variances and their errors for each character of the three double crosses with t values for comparing the mean variances.*

Character	D.C. A (25×71) (111×158)	D.C. B (25×111) (71×158)	D.C. C (25×158) (71×111)	t values for comparison of variances in double crosses		
				A–B	A–C	B–C
Moisture	26.2±2.82	29.2±2.94	20.6±2.33	0.74	1.53	2.20*
Date silked	7.5±0.78	13.8±1.72	6.9±0.75	3.37†	0.58	3.71†
Date pollen shed	4.1±0.43	5.1±0.54	3.8±0.41	1.43	0.39	1.80
Ear height	23.5±2.56	27.5±2.95	21.8±2.29	1.03	0.50	1.54
Plant height	36.1±3.81	48.3±5.35	35.7±3.71	1.86	0.07	1.94
Ear leaf area	131.3±13.70	195.3±21.13	148.6±16.33	2.54*	0.81	1.75
Ear length	1.02±0.14	1.01±0.11	0.76±0.08	0.06	1.63	1.79
Row number	4.1±0.45	4.75±0.50	4.2±0.45	0.90	0.08	0.82

*t value of 1.97 required for significance at the 5% level.
†t value of 2.6 required for significance at the 1% level.

It appears then that double cross C, (25 × 158) (71 × 111) has a tendency to be the most uniform of the three double crosses for all characters, including ear length and row number. Double cross B, (25 × 111) (71 × 158), exhibits an equal tendency to be the most variable of the three. Double cross A, (25 × 71) (111 × 158), which was expected to be most uniform was intermediate to B and C for variability of most of the characters but on the average was only slightly more variable than double cross C.

DISCUSSION

A late inbred is thought of as carrying genes for lateness while an early inbred has genes for earliness. A cross between such lines results in a uniform single cross intermediate in maturity. On this basis a double cross of the type (E × E) (L × L) is expected to be relatively uniform and intermediate in maturity.

However, in a double cross of the (E × L) (E × L) type, opportunity for segregation of genes for maturity would appear to be present and such a double cross is expected to be more variable than the first in such characters as date of silking and percentage of ear moisture. Whether such differences are obtained in most crosses of this type and the extent of the differences is of practical importance.

In this particular study the expected differences did not materialize. The most uniform double cross was one of the two (E × L) (E × L) types. The other member of this pair behaved according to expectation and was consistently the most variable of the three doubles.

Such irregular results serve to emphasize the complexity of inheritance in quantitative characters.

Characters of the type that were studied here are known to be controlled by several to many genes. Unrelated inbreds which look alike for a particular character very probably differ in some of the genes governing the expression of the character so that in a double cross of the (E $\times$ E) (L $\times$ L) type the opportunity for segregation is present.

In this study it appeared impossible to predict the relative variability of the double crosses on the basis of the means of the non-parental single crosses. It is entirely possible that many promising double crosses have been discarded in the past because of wide differences in certain characters of the single crosses which were used to predict double cross yields.

SUMMARY

Plant-to-plant variability was studied in the three possible double crosses from four inbred lines. These inbreds were unrelated and differed widely in several quantitative characters.

It did not appear possible to predict the relative variability of the double crosses on the basis of the character means of either inbreds or single crosses.

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STUDIES ON SUSCEPTIBILITY OF VARIETIES AND STRAINS OF BARLEY TO *FUSARIUM* AND *HELMINTHOSPORIUM* KERNEL BLIGHT WHEN TESTED UNDER MUSLIN TENTS OR IN NURSERIES[1]

F. R. IMMER AND J. J. CHRISTENSEN[2]

HEAD or kernel blight of barley caused primarily by *Helminthosporium sativum* P.K. and B. and *Gibberella zeae* (Schw.) Petch is one of the most destructive diseases of barley in the north central region of the United States. Losses are sometimes extremely high. Yields may be greatly reduced, but greater losses probably result from the low quality of the grain.[3] Some varieties are more resistant than others and some progress is being made in breeding for disease resistance. Among the six-rowed varieties of barley which have some resistance to kernel blight are Peatland, C.I. 5267; Chevron, C.I. 1111; Korsbyg, C.I. 918; and two unnamed varieties, C.I. 2492 and C.I. 1613. Of these, Peatland is the only variety grown commercially in the United States.

Over a period of several years, it has been the practice at Minnesota to test separately the varieties and strains of barley for resistance to Fusarium and Helminthosporium blight, both under muslin tents and in field nurseries. Obviously, this involves considerable time and labor. Consequently, it is of considerable practical importance to determine whether the reaction of these varieties was similar to both types of blight and whether reaction to these diseases leads to the same varietal differentiation in tests under a muslin tent as in tests in the nursery, without cover. This paper is concerned with an analysis of data which provides information on the above two problems.

MATERIAL AND METHODS

In this paper "Fusarium blight" will refer to the blight caused by several species of Fusarium, chiefly by *F. graminearum* Schwabe (*Gibberella zeae*), and "Helminthosporium blight" will refer to kernel blight caused by a group of organisms other than Fusarium, particularly *Helminthosporium sativum*. Although extensive isolations and inoculation tests have shown that many species of *Fungi Imperfecti* can induce discoloration and blighting of kernels, *Fusarium* spp. and

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[3]CHRISTENSEN, J. J., and STAKMAN, E. C. Relation of Fusarium and Helminthosporium in barley seed to seedling blight and yield. Phytopath., 25:309-327. 1935.

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Helminthosporium spp. are the pathogens primarily responsible for shrivelling and blighting of barley seed in Minnesota.[4]

Strains of barley in advanced generations and certain F_4 and F_5 selections from the regular breeding nursery were grown in four series of duplicate plots. Two of the tests were conducted in muslin tents, the covers being put on soon after the awns emerged from the earliest maturing varieties and left in place until the final notes were taken. The heads of barley in one tent were sprayed with a water suspension of conidia from *Fusarium* spp., while the plants in another tent were sprayed with spores of *Helminthosporium* spp. and certain other *Fungi Imperfecti* except *Fusarium*. Inoculations were made usually during moist weather or late in the afternoon. The strains were grown also in nursery plots without covers and sprayed an equal number of times with *Fusarium* or *Helminthosporium*. Since high humidity is very conducive to the development of kernel blight, the ground, whenever it became dry, was sprinkled or soaked with water.

Notes on date of heading were taken at the time of awn emergence. Data on percentage of *Fusarium* and *Helminthosporium* blights were based on estimates of the percentage of kernels injured by the pathogens. These notes were taken as the grain began to turn color in ripening and are based on estimates made independently by two individuals.

EXPERIMENTAL RESULTS

The results for this study were obtained during the seasons of 1937–39 and only the data from those strains which had been tested for their reaction to *Fusarium* and *Helminthosporium* blight in both tents and nurseries and for more than one year were used. Only tests were used in which the range in percentages of blight of the strains was of such a magnitude that accurate differentiation in disease reaction could be made.

Experiments made over a period of years indicate that the percentage of blight obtained usually is correlated negatively with date of heading, particularly in tests made in tents, the percentage of blight of both types decreasing as date of heading is delayed. As a consequence, the late strains of barley often appear to be more resistant than the early ones, due to late heading.

Analyses of variance and covariance were calculated for *Fusarium* or *Helminthosporium* blight and date of heading in each separate test. The regression of *Fusarium* or *Helminthosporium* blight on date of heading for the "strain" component was calculated and the sums of squares of *Fusarium* or *Helminthosporim* blight adjusted for regression. The adjustment was calculated from $S(y-\bar{y})^2 - 2bS(y-\bar{y})(x-\bar{x}) + b^2S(x-x)^2$, where $S(y-y)^2$ was the unadjusted sum of squares for *Fusarium* or *Helminthosporium* blight, $S(x-\bar{x})^2$ was the sum of squares for date of heading, and $S(x-\bar{x})(y-\bar{y})$ was the sum of products. The strain regression, b, was used to correct both the strain and error sums of squares. The adjusted sums of squares and mean squares will then measure the variation in *Fusarium* or *Hel-*

[4]In this paper because of simplicity, the plants in the tent and nursery inoculated with *Fusarium* species will be referred to as *Fusarium* or "F", tent and nursery, respectively, while those inoculated with *Helminthosporium* and other *Fungi Imperfecti* except *Fusarium* will be designated as *Helminthosporium*, or "H", tent and nursery, respectively.

minthosporium blight remaining after correction for date of heading. The adjusted mean squares for the separate tests are given in Table 1, with the mean percentage of *Fusarium* or *Helminthosporium* blight of the entire test and the value of the regression of *Fusarium* or *Helminthosporium* blight on date of heading.

TABLE 1.—*Analysis of variance of reaction of barley varieties and strains to Fusarium or Helminthosporium blight, mean percentage of blights, and regression coefficient of blight on date of heading.*

Variation due to	D.F.	Adjusted mean square for *Fusarium* and *Helminthosporium* blight†					
		F, tent, 1939	F, nursery, 1939	H, tent, 1939	H, nursery, 1939	F, nursery, 1938	H, tent, 1938
Strains	43	300.00**	103.5*	121.9**	59.2**	261.8*	209.5*
Error	44	78.3	56.6	44.1	26.9	151.8	115.2
		Mean *Fusarium* or *Helminthosporium* blight and regression of *Fusarium* or *Helminthosporium* blight on date of heading					
Mean		76.8	19.0	26.7	10.7	37.4	34.4
b		−3.4790**	+0.7214	−0.6120	+0.4521	−5.2943**	−2.7786**

		Adjusted mean square for *Fusarium* and *Helminthosporium* blight			
		H, tent, 1938	F, nursery, 1938	F, tent, 1937	H, tent, 1937
Strains	52	191.8	301.4*	341.5**	319.2**
Error	53	126.2	178.7	140.7	125.0
		Mean *Fusarium* or *Helminthosporium* blight and regression of *Fusarium* or *Helminthosporium* on date of heading			
Mean		34.7	37.5	47.3	53.8
b		−2.7688**	−4.7358**	−4.1411**	−7.0868**

*Exceeds the 5% point.
**Exceeds the 1% point.
†F = Fusarium; H = Helminthosporium.

Thirty of the 45 strains analyzed in the upper part of Table 1 are included in the 54 strains in the lower part of the same table. The degrees of freedom for strains have been reduced by one because of adjustment by means of the strain regression.

There was significant variation in reaction of the strains after adjustment for date of heading in all tests, except the 54 varieties tested for *Helminthosporium* blight in a tent in 1938.

The mean percentage of *Fusarium* or *Helminthosporium* blight in

the different tests varied from 10.7 for the *Helminthosporium* nursery[5] in 1939 to 76.8 for the *Fusarium* tent in 1939. The regression coefficients varied from +0.7214 to −7.0868. The latter indicates that as the date of heading in the tent was delayed 1 day the average reduction in amount of blight was 7%. Selection of strains for resistance to blight without a consideration of the effect of date of heading would result in the selection, very largely, of late-heading strains, with a regression of such magnitude. It is the plan at Minnesota in breeding for resistance to scab or the kernel blight to adjust the percentage blight on the basis of date of heading, the adjustment being given by $y - b(x - \bar{x})$, where y is the observed percentage of *Fusarium* or *Helminthosporium* blight, x is the date of heading expressed as number of days after June 1, and b the regression coefficient. On this basis the strains are selected which are more resistant than would be expected from the average relationship between *Fusarium* or *Helminthosporium* blight and date of heading. With a significant negative regression between amount of disease and date of heading, the early strains would be penalized in selection if no adjustment were made for date of heading. In this study it is clear that significant differences in reaction of varieties of barley to blight exist and it would appear that progress in breeding for disease resistance can be made.

In Table 2 is given the mean percentage of *Fusarium* or *Helminthosporium* blight, adjusted for date of heading, in six different tests for 18 of the varieties and strains tested as an example of the results obtained.

TABLE 2.—*Mean percentage of Fusarium or Helminthosporium blight adjusted for date of heading for 18 varieties or strains.*

Variety or strain	Nursery stock No.	F, tent, 1939*	F, nursery, 1939	H, tent, 1939*	H, nursery, 1939	F, nursery, 1938	H, tent, 1938	F, tent, 1937	H, tent, 1937
Peatland	452	42	0	8	1	27	26	32	34
Velvet	447	90	17	34	5	17	44	36	50
Barbless	529	86	23	31	15	20	26	44	30
Minn. No. 462 × Peatland	II–31–3	90	24	32	12	37	54	44	50
Minn. No. 462 × Peatland	–15	94	23	36	11	46	47	60	76
Minn. No. 462 × Peatland	–16	98	24	36	12	37	45	72	60
Minn. No. 462 × Peatland	–18	72	16	23	8	41	48	63	39
Minn. No. 462 × Peatland	–19	75	24	26	9	42	33	70	48
Minn. No. 462 × Peatland	–25	88	25	33	11	45	37	44	50
Minn. No. 462 × Peatland	–44	85	13	21	4	38	31	55	67
Minn. No. 462 × Peatland	–45	76	11	22	6	29	34	56	66
Minn. No. 462 × Peatland	–46	83	25	36	13	52	44	59	73
Minn. No. 462 × Peatland	–48	67	12	15	5	16	26	28	48
Minn. No. 462 × Peatland	–49	69	16	35	9	26	31	33	52
Minn. No. 462 × Peatland	–50	74	24	28	8	35	28	38	54
Minn. No. 462 × Peatland	–56	80	13	23	11	36	46	38	49
Minn. No. 462 × Peatland	–71	46	12	12	2	29	41	43	53
Minn. No. 462 × Peatland	–74	80	10	17	5	27	22	35	55

*F = Varieties inoculated with *Fusarium* spp.; H = Varieties inoculated with *Helminthosporium* spp., etc.

[5]See footnote 4.

It is noted that the variety Peatland had a relatively low percentage of infection in all tests. The strain II-31-71 was slightly more susceptible than Peatland and was lower than the average of all strains in seven of the eight tests. On the other hand, strain II-31-16 had a higher percentage of infection by both types of blight in seven tests and equalled the mean in the *Fusarium* nursery in 1938. It appears that strains can be isolated from hybrids between susceptible and resistant varieties which have an appreciable degree of resistance to *Fusarium* and *Helminthosporium* blight.

In order to determine whether the reaction of these strains of barley to *Fusarium* and *Helminthosporium* blight was the same and whether the reactions in tent and nursery were the same or differential, the data from two experiments were combined and the interaction of strains with the type of test tested for significance.

An exact test of significance of the interaction of the 54 strains of barley tested in a *Fusarium* tent in 1937 and a *Helminthosporium* tent in 1937 will be illustrated.[6] In Table 3 are given part of the data and the manner of calculation.

TABLE 3.—*Difference in percentage of Fusarium blight in tent 1937 and Helminthosporium blight in tent 1937 and date of heading in each test, data for sum of two replications per test.*

Variety or strains	H blight minus F blight (y)*	Date of heading		yx_1	yx_2	x_1x_2
		H, tent x_1	F, tent x_2			
Peatland	1	59	65	——	——	——
Velvet	20	52	52	——	——	——
Barbless	20	51	64	——	——	——
Minn. No. 462×Peatland, II-31-3	10	52	53	——	——	——
Minn. No. 462×Peatland, II-31-7	25	49	50	——	——	——
Minn. No. 462×Peatland, II-31-8	45	49	50	——	——	——
Sum	709	2,875	3,016	——	——	——
Squares or products	55,495	154,043	170,060	34,980	37,327	161,602
Correction term	9,309	153,067	168,449	37,748	39,599	160,574
Sum or squares or products	46,186	976	1,611	−2,768	−2,272	1,028
Sum of squares÷4	11,546	244	403	−692	−568	257

*See footnote 4.

The sums of squares need to be divided by 4 (in general, by 2k where k is the number of plots per strain) since y was based on the difference between totals of two plots each.

A multiple regression was calculated with the difference between *Helminthosporium* and *Fusarium* blight of the different strains as the dependent variable. This was calculated from the equations:

$$b_1S\,(x_1-\bar{x}_1)^2 + b_2S\,(x_1-\bar{x}_1)\,(x_2-\bar{x}_2) = S\,(y-\bar{y})\,(x_1-\bar{x}_1)$$
$$b_1S\,(x_1-\bar{x}_1)\,(x_2-x_2) + b_2S\,(x_2-\bar{x}_2)^2 = S\,(y-\bar{y})\,(x_2-\bar{x}_2)$$

[6]Method suggested by Prof. W. G. Cochran, Iowa State College, Ames, Iowa.

Substituting the sums of squares and products obtained from Table 3:

$$244\, b_1 + 257\, b_2 = -692$$
$$257\, b_1 + 403\, b_2 = -568$$

From which $b_1 = -4.1168$ and $b_2 = 1.2159$.

The adjusted sum of squares of y (difference between *Helminthosporium* blight and *Fusarium* blight) will be

$$S\,(y-\bar{y})^2 - b_1 S\,(y-\bar{y})\,(x_1-\bar{x}_1) - b_2 S\,(y-\bar{y})\,(x_2-\bar{x}_2)$$

Substituting:

11,546 − (−4.1168) (−692) − (1.2159) (−568) = 9388 as the sum of squares for interaction of strains and type of test (*Helminthosporium* vs. *Fusarium* blight) with 51 degrees of freedom, the degrees of freedom being reduced by 2 because of the two independent variables. Dividing, 9,388 by 51 gives 184.1 as the adjusted mean square. As an error with which to compare this interaction mean square, we may use the average error mean square for the separate tests as given in Table 1. The average of 140.7 and 125.0 is 132.8. The interaction mean square, 184.1, divided by 132.8 gives $F = 1.39$, a nonsignificant value for $n_1 = 51$ and $n_2 = 106$ degrees of freedom.

An approximate test can be made more easily. In Table 4 are given the mean squares of variance calculated from the adjusted strain means, the analysis of which was given for the individual tests in Table 1. For example, the 54 strains tested for reaction to *Fusarium* blight in a tent in 1937 and to *Helminthosporium* blight in a tent in 1937 were combined and an analysis of the adjusted means, yielding 1 degree of freedom for scab vs. blight, 51 degrees of freedom for strains, and 53 degrees of freedom for interaction obtained. The degrees of freedom for strains is reduced by two since each separate test was adjusted for regression of scab or blight on date of heading. The error to be used, 132.8, is the average mean square for error of the separate tests (Table 1). Such approximate tests for various combinations of *Fusarium* and *Helminthosporium* blight, both in a tent and in the nursery, are given in Table 4.

From this approximate test it is seen that the strains of barley differed significantly in every comparison. The mean square for interaction for the *Fusarium* tent 1937 vs. the *Helminthosporium* tent 1937 for 54 strains was 198.2. The exact test illustrated previously gave an interaction mean square of 184.1. The approximate test (Table 4) for the *Fusarium* tent 1939 vs. the *Fusarium* nursery 1939 yielded a mean square for interaction of 135.5 where the exact test gave 133.8. The approximate method appears to be sufficiently accurate for the comparisons to be made.

In 7 of the 11 comparisons made in Table 4 the interaction was nonsignificant, indicating a lack of significantly differential response to *Fusarium* and *Helminthosporium* blight in tent and nursery. In both comparisons involving the *Fusarium* tent in 1939 the interaction was highly significant. The mean percentage of *Fusarium* blight in the tent in 1939 was 76.8, while the mean percentages of *Fusarium* or *Helminthosporium* blight in the tent in 1939, with which they were

compared, was 19.0 and 26.7, respectively. A significant interaction may be due to real differential response or to a difference in variance of the strains of the two tests being compared. It is seen in Table 1 that the strain variance for the *Fusarium* tent in 1939 was 300.0, while the strain variances for the *Fusarium* nursery and *Helminthosporium* tent in 1939 were 103.5 and 121.9, respectively. It is probable that a large part of the interaction variances for comparisons involving the *Fusarium* test in 1939 was due to the difference in strain variances in the separate tests.

TABLE 4.—*Analysis of variance of reaction to Fusarium and Helminthosporium blight in different experiments, approximate tests of significance.*

Variation due to	D.F.	F, tent, 1939, and F, nursery, 1939†	H, tent, 1939, and H, nursery, 1939	F, nursery, 1939, and H, nursery, 1939	F, tent, 1939, and H, tent, 1939	F, nursery, 1938, and H, tent, 1938	F, nursery, 1938, and H tent, 1939	F, nursery, 1938, and H, nursery, 1939
Strains......	42	268.1**	138.9**	136.0**	303.5**	369.8**	224.0**	170.0**
Interaction..	44	135.5**	42.5	26.7	118.9**	101.8	160.4*	151.2*
Error.......	88	67.4	35.5	41.8	61.2	133.5	98.0	89.4

		H, tent, 1938, and F, nursery, 1938	H, tent, 1938, and F, tent, 1937	H, tent, 1938, and H, tent, 1937	F, tent, 1937, and F, nursery, 1938	F, tent, 1937, and H, tent, 1937
Strains......	51	344.3**	387.2**	345.9**	452.5**	458.3**
Interaction..	53	139.1	143.9	155.4	186.1	198.2
Error.......	106	152.4	133.4	125.6	159.7	132.8

*Exceeds the 5% point.
**Exceeds the 1% point.
†See footnote 4.

An interaction is a difference between differences. The proper standard error for such interaction comparisons of two varieties tested for *Fusarium* blight in tent and nursery in 1939 would be

$$\sqrt{\frac{67.4 \times 2 \times 2}{2}} = 11.6,$$ where 67.4 is the mean square for error of these two combined tests in Table 4. Comparing Velvet and Peatland in *Fusarium* tent and nursery in 1939 gives (90–42)–(17–0) = 48–17 = 31±11.6. This "cross" difference is significant. A similar comparison of Velvet and II-31-71 gives (90–46) – (17–12) = 44–5 = 39±11.6. Comparing II-31-3 with II-31-71 in these two tests gives (90–46) – (24–12) = 44–12 = 32±11.6. Other statistically significant interactions may be found. It is to be noted that the cross difference is significant because the difference between resistant and susceptible strains was greater in the tent than in the nursery. The strains in the comparisons made above were in the same order for reaction under the two types of tests.

In the comparisons of the *Fusarium* nursery 1938 with the *Helminthosporium* tent 1938 and of the *Fusarium* nursery 1938 with the *Helminthosporium* nursery 1939, the interactions exceeded the 5% level of significance. In both these comparisons the strain variance for one of the tests was at least twice as large as the other. This would tend to give a high interaction mean square. It is probable that had the variation in reaction in the separate tests been relatively the same, the interaction would have been nonsignificant.

It seems apparent that reaction to *Fusarium* blight, caused chiefly by races of *F. graminearum* and *Helminthosporium* blight, caused chiefly by *H. sativum*, is essentially the same with the technic used in these experiments. Therefore, the testing of barley to the pathogens causing *Fusarium* blight also will serve to isolate strains of barley resistant to other groups of organisms that cause shriveling and blighting of barley kernels. This type of blighting should not be confused with brown and black discolorations induced by bacteria and certain weakly parasitic fungi.

SUMMARY

1. Strains and varieties of barley were tested separately for disease reaction to *Fusarium* and *Helminthosporium* kernel blight, both in a tent and in a field nursery.

2. In 7 of 10 tests made in tents a significant negative regression of *Fusarium* or *Helminthosporium* blight on date of heading was obtained. In the tents the susceptibility of variety to blight is usually correlated with the date of heading.

3. In 9 of the 10 tests the strains differed significantly in reaction to *Fusarium* or *Helminthosporium* blight after adjustment for date of heading.

4. When the variation among strains tested for reaction to *Fusarium* and *Helminthosporium* blight was not materially different, there was no significantly differential response to *Fusarium* and *Helminthosporium* blight in a tent or nursery.

5. Selection for blight resistance in tents without consideration of date of heading would lead to selection of late-heading strains, not necessarily resistant to blight.

6. In general, varieties resistant to *Fusarium* blight also were resistant to *Helminthosporium* blight.

GROWTH RELATIONSHIPS AS AFFECTING ROOT ROTTING AND PREMATURE DEATH OF SWEET CLOVER[1]

J. M. SLATENSEK AND E. A. HOLLOWELL[2]

SEVERE rotting of roots and crowns of second-year sweet clover plants has occurred annually for several years in space-planted breeding nurseries at Lincoln, Nebr.[3] Similar difficulties have been experienced at several other agricultural experiment stations. This condition is seldom found in fields of sweet clover.

While the end-result is a rotting of the roots and crown, the studies reported in this paper indicate that the primary cause is a physiological disturbance due to excessive first-year growth. Many of the second-year nursery plants die and most of the remaining ones are so malformed that observations on growth characteristics are of little value. Seed production is greatly impaired. These studies are concerned with the cause and control of the trouble.

SYMPTOMS

The first noticeable above-ground symptons of the diseased condition appear on second-year plants in early spring when the overwintering crown buds begin their development. Many of these buds fail to grow; others start normally, but subsequent growth may show symptoms at any time up to seed production. One or more shoots of the same plant may wilt, turn yellowish, and die. Usually several days elapse between the wilting and the death of the shoot. Plants may die at all stages of growth from early spring through the flowering period and even during seed setting. Examination of the roots, crowns, and basal sections of shoots upon removal from the soil reveals varying degrees of rotting (Fig. 1). The roots and crowns of such nursery-grown plants are abnormally enlarged and the tissue is soft and flaccid. Cracks and necrotic areas of various sizes are frequently found in the fall on these overgrown roots. Small lateral roots arising from the main tap roots of normal plants are conspicuously absent on the diseased roots.

EXTENT OF LOSSES

During 1940 and 1941 the second-year plant nurseries were surveyed and the plants were classified according to the extent of injury.

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[3]The practice heretofore at Lincoln has been to start the seedlings in asphalt paper bands in the greenhouse in early March and then to transplant these into the 3 × 3 foot spaced plant nursery in the field in April.

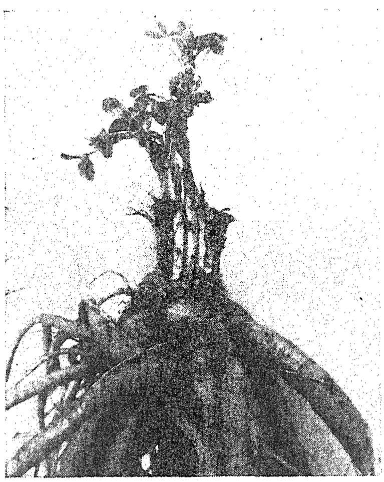

FIG. 1.—Typical appearance of affected plants in the spring of the second year of growth.

The results are given in Table 1. Although the data consider only some of the more common varieties and species, disease notes were also taken on the minor species growing in the observation nursery. The number of plants of these species was limited but, with the exception of *Melilotus taurica*, all proved to be highly susceptible.

Surveys of farm fields in southeastern Nebraska were made in 1939 and 1940 to determine if such a diseased condition was present. No significant amount of the disease was found. Characteristic root rotting was found in widely spaced roadside and other scattered volunteer plants. This may have been *Phytophthora* root rot, however. In 1942 approximately 5% of the plants in a seed-increase field of Spanish sweet clover died from root rot in their second year. These plants had made an extremely large first-year growth due to a 3-foot row spacing and the favorable climatic conditions prevailing in 1941.

TABLE 1.—*Amount of root rotting in different species and varieties of sweet clover (Melilotus) in second-year nurseries at Lincoln, Nebr., in 1940 and 1941.*

Variety	Species	No. of plants	Dead %	Severely diseased	Slightly diseased	Apparently healthy
				%	%	%
Redfield........	*suaveolens*	668	47	38	14	1
Chantland......	*alba*	1,116	53	18	13	16
Evergreen......	*alba*	1,785	57	21	13	9
Common yellow	*officinalis*	45	58	14	20	8
Madrid........	*officinalis*	207	60	24	13	3
Siberian........	*suaveolens*	1,707	60	17	16	7
Spanish........	*alba*	2,157	71	14	8	7
Fowlds.........	*alba*	816	78	9	6	7
Total........		8,501	62	18	12	8

EXPERIMENTAL

In 1939 preliminary studies[4] were undertaken in an attempt to determine the effect of different-sized transplanting containers, methods of cultivation, and method of starting the seedlings on the incidence of the disease. Both the species

[4]The writers are indebted to Samuel Garver, Associate Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, for permission to use this summary of unpublished data obtained by him.

Melilotus alba and *M. officinalis* were represented in this investigation by using common biennial white, common biennial yellow, and a selection of Fowlds, *M. alba*. A summary of these results recorded in the spring of 1940 are as follows:

1. There was no significant difference between the use of shallow (4-inch) asphalt paper bands compared with deep (8-inch) bands for starting the plants in the greenhouse.

2. No significant difference in plant survival resulted from shallow vs. deep cultivation of the nursery plants.

3. Starting the plants from seed sown directly into the nursery in rows 3 feet apart in April and thinned in June resulted in better survival than where the plants were started in bands in the greenhouse in March and transplanted in April.

4. In all treatments the common biennial yellow showed greater resistance to root-rotting than did common biennial white and Fowlds, the average percentage of survival for the three varieties being 66, 48, and 26, respectively.

The results of this study and of observations on the growth and root development of other sweet clover plantings suggested the possibility of an association between excessive first-year growth and root-rotting. The following investigation was designed primarily to determine whether such a relationship existed.

TREATMENTS TO REGULATE GROWTH

Open-pollinated seed of the varieties and species listed in Table 1 was used for the most part in these plantings and treatments, with the exception noted below. The objective of the treatments was to regulate the amount of growth made the first year by means of spacing distances, time of seeding, and reduction of photosynthetic area. The following treatments formed the basis for this study:

1. Plants that were closely spaced, the seed having been drilled solid in the field in April, in accordance with the usual farm procedure.

2. Plants that were started from seed sown late in the nursery on July 13. These plants were spaced 3 feet by 3 feet.

3. Plants that were started from seed sown in 4-inch asphalt felt roofing paper bands in the greenhouse in early March and then transplanted to the 3 × 3 feet spaced plant field nursery in April. This had been the customary method of handling the nursery plants.

4. Plants that were handled the same as those in No. 3, but were kept trimmed to 8-inch stem lengths after June 26, 1940, in order to reduce their photosynthetic area. This group consisted of 22 different inbred lines of three different varieties. One half of the plants of each line were kept trimmed while the other half were allowed to develop without artificial retardation.

Records of growth were made the first year. In November roots of plants selected at random from the various treatments described above were dug, classified as to size, and critically examined as to condition. Specimens were preserved for anatomical examination.

RESULTS

The amount of first-year growth of plants grown under the various treatments differed widely. In general, the spaced, transplanted nursery plants of any variety were from 25 to 50 times larger than those grown in solid seedings. Representative roots of the different treatments are shown in Fig. 2. Although the number of roots

examined was limited, there was an inverse relationship between the healthy condition of the tissue and increased root size. The roots from the plants that were spaced and transplanted early were overgrown, soft, subject to splitting, and frequently showed varying degrees of necrosis. On the other hand, the smaller, normal sized roots were firm and clean and the tissue showed no sign of breaking down. The roots of plants that were trimmed to reduce the photosynthetic area were decidedly more healthy than comparable roots from untrimmed plants. It should be mentioned here that the defoliation treatment was started on June 26, 1940, at which time the plants had already made considerable growth. This may have had some effect by decreasing proportionally the number of sound roots.

SECOND-YEAR GROWTH

During the spring and summer of the second year, records were made on the condition of the growth at periodic intervals. The results

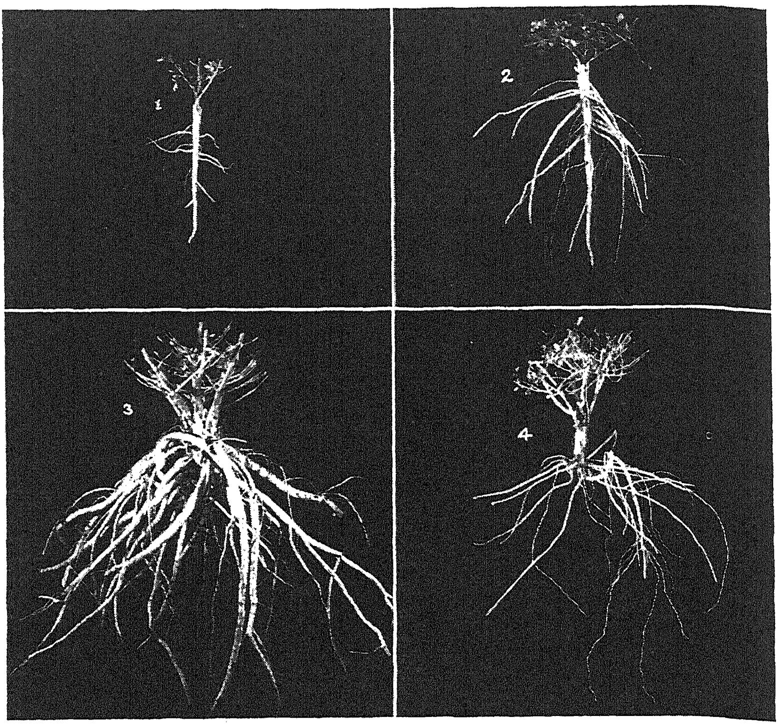

FIG. 2.—Representative roots of plants grown under different growth regulating treatments as they appeared on Nov. 5 of their first year of growth. 1, plant from April seeding, solid drilled; 2, plant started from seed sown late (July 13) in 3×3 feet spaced nursery; 3, plant handled in customary nursery manner, i.e., started early in greenhouse and then transplanted to the 3 × 3 feet spaced nursery in April; 4, plant handled the same as No. 3 but kept trimmed to 8-inch stem lengths after June 26.

TABLE 2.—*Summary of results of the influence of controlled type of first-year vegetative growth on incidence of root rotting in sweet clover at Lincoln, Nebr., 1940–41.*

Group No.	Growth controlled by		Approximate relative size of plants*	No. of plants	Condition of roots at end of first year	Second-year counts		
	Manner of seeding	Manner of spacing				Plants dead, %	Plants alive but diseased, %	Plants apparently healthy, %
1	Drilled in field early (April)	Solid	1	10,000	Healthy	0	0	100
2	Seeded late (July 13) in nursery	Wide (3×3 feet)	1	84	Healthy	0	0	100
3	Seeded early March in greenhouse, transplanted to nursery in April	Wide (3×3 feet)	30	6,155	Diseased	59	32	9
4	Same as (3) but kept trimmed after June 26	Wide (3×3 feet)	10	156	Diseased and healthy	17	37	46

*Based on the average amount of vegetative top growth of plants drilled in field early (April) as 1; other figures indicate the number of times larger than 1.

of these studies are summarized in Table 2. In order to test further the assumption that excessive first-year growth was primarily responsible for their diseased condition, the association between the above-ground size of first-year plants and premature second-year mortality was determined. Estimations on the size of the first-year vegetative growth were made using a relative numerical class basis of 1 to 10 (1 = the smallest growth; 10 = the largest growth). The size designations were determined by comparing the individual plants of a given variety under the same growth treatment. The results as presented in Fig. 3 show a positive relationship between the large size of first-year plants and an increase in plant mortality.

FIG. 3.—Relation between premature death of nursery sweet clover plants and their maximum first-year plant size in the 1940–41 breeding nurseries at Lincoln, Nebr.

TABLE 3.—*Effect of first-year flowering on incidence of root rotting during the second year, Lincoln, Nebr., 1940–41.*

Plants	Number	Dead %	Severely diseased %	Slightly diseased %	Apparently healthy %
Blooming..........	352	57	22	15	6
Nonblooming.......	5,903	59	18	14	9

EFFECT OF FIRST-YEAR FLOWERING ON PREMATURE MORTALITY

The production of flowers on the first-year growth of biennial sweet clover is of infrequent occurrence in farm fields. Such flowering,

however, was found to occur to a much greater extent in the wide-spaced, early-established nursery populations. Some of these nursery plants bore only a few racemes, while others bloomed rather profusely. It was not known if flowering had an effect on the diseased condition and plants were classified accordingly in late summer and the following spring. The results as given in Table 3 clearly indicate that flowering the first season had no effect on the incidence of root rotting.

COMPARISON OF NORMAL AND ABNORMAL ROOT STRUCTURE

Sections of normal and abnormal roots were examined microscopically and the results as shown in Fig. 4 indicate that the increased size of the abnormal roots was due mainly to an increased number of cells, although the size of the cells, especially the parenchyma, was also increased. Another apparent difference is in cell wall thickness, the cell walls of the overgrown roots being thinner than those of the normal plant.

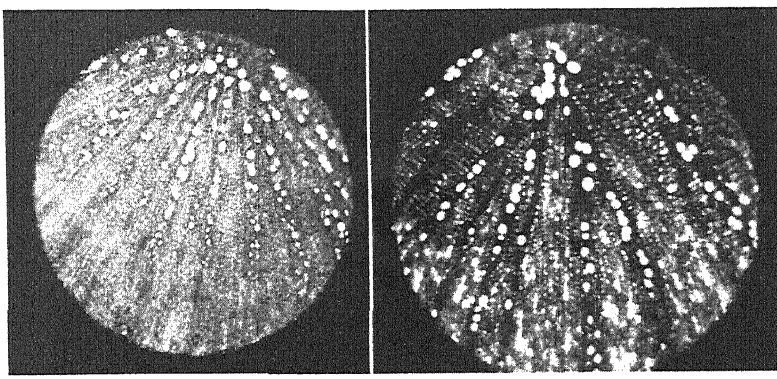

FIG. 4.—Transections through secondary xylem of normal, healthy root (left) and overgrown, diseased root (right). × 50.

DISCUSSION

In view of the results obtained from this investigation the sweet clover plants in the 1941–42 breeding nursery at Lincoln were handled in such a manner that they did not make excessive growth during their first year. This was accomplished by starting the plants in late spring and transplanting in late June and early July. As a consequence, their size at the end of the first year more nearly approached that of plants in close seedings with the result that no root rot occurred during the second year. At Urbana, Ill., the seeding of a companion grain crop at a light rate per acre after transplanting the sweet clover has retarded the first year's growth. The use of sudan grass or millet also has possibilities for this purpose.

The reason why excessively large sweet clover roots are more susceptible to root rotting is not known. It appears that changes in the normal environmental relations, such as removal of plant compe-

tition or greatly increasing the supply of water and other nutrients, result in profound alterations in the structure and physiology of the plant. It is possible that such disturbances lower the resistance of plants making them susceptible to invasions of parasitic fungi. There is also the possibility that excessive root growth results in disturbances of such a magnitude that degeneration, in some respects like senescence, sets in. The presence of parasites would then be unnecessary. Saprophytes could cause the rotting after host breakdown had occurred, due to effects other than the initial reactions produced by invading parasites. Fall and spring isolations from abnormal roots at Lincoln, Nebr., and at Madison, Wis., by Dr. F. R. Jones,[5] show that a number of fungi can be obtained from the rotting roots. These have not proved to be pathogenic when used in the inoculation of normal sized, healthy roots. It is evident, therefore, that the disease is not the *Phytophthora* root rot of sweet clover known to occur in this region.

SUMMARY

1. Severe outbreaks of a heretofore unexplained root- and crown-rotting disease have occurred annually since 1938 in populations of widely spaced plants in the sweet clover breeding nurseries at the Nebraska Agricultural Experiment Station. Annual mortality has amounted to approximately 60% of the second-year plants and most of the remaining plants have shown varying degrees of abnormality.

2. Above-ground symptoms of the disease appear mainly in the spring of the second year of plant growth. Wilting and yellowing of all or part of the plant is usually followed by death. The roots of affected plants are characterized by being overgrown and soft and they contain necrotic areas of various sizes. Initial rotting occurs in the crown and upper part of the root.

3. Studies of the effect of controlled first-year growth on disease incidence disclose that the condition is a result of excessive first-year growth. First-year plant size was regulated by means of spacing distances, time of seeding, and reduction of photosynthetic area through removal of top growth. Disease notes taken during the second year on these differently treated plants showed that (a) plants whose growth was restricted by any means to approximate that in farm stands were free from root and crown rot; and that (b) widely spaced plants which were allowed to develop to a size corresponding with that of the large, regular nursery-grown plants were severely root- and crown-rotted.

4. Comparative anatomical studies on normal and abnormal roots showed the latter to be comprised of more as well as larger cells. Also, the cell walls of the overgrown roots appeared to be thinner than those of the smaller normal roots.

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[5]The writers are indebted to Dr. F. R. Jones, Senior Pathologist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, for making the isolations and inoculations with these fungi.

5. Control measures for the disease consist of growing the nursery plants in such a manner that they do not develop excessively during their first year. In the 1941–42 breeding nursery this was accomplished by starting the widely spaced plants in late spring and transplanting in late June and early July. A second-year nursery entirely free from the root rot was the result.

FACTORS AFFECTING MILLING QUALITY IN OATS[1]

RICHARD E. ATKINS[2]

THE prominent position of the oat crop in most farming areas is justified by its value as a feed for farm animals and by its adaptability to the common crop rotation systems. Only two other cereal crops grown in the United States, namely, corn and wheat, exceed oats in acreage and value. A small portion of the oat crop is marketed directly and processed into rolled oats or oatmeal and other oat products for use as human food. High quality grain is essential for the most economical processing into these products; therefore, any morphological or agronomic characters associated with milling value are of importance in evaluating varieties or selections.

Although previous studies on quality of the oat crop have been made with regard to its value as a feed for livestock, the same criteria may be applicable in a consideration of oats milled for human consumption. The percentage of hull and bushel weight are the quality factors that have been most fully investigated. The percentage of hull is universally agreed upon as one of the most important quality characters of an oat variety. The value of test weight per bushel, however, is not as uniformly agreed upon by the different workers.

Love (4)[3] determined the hull percentage of a large number of oat varieties and found it to range from 25 to 40. Zavitz (9) found a slightly wider range, 21 to 43%, in a study that extended over a 20-year period. With but few exceptions those varieties that were high or low in a given year performed similarly in other years.

A wide difference of opinion is apparent as to the value of test weight as an indication of quality in oats. Stoa, *et al.* (7) found the percentage of hull closely correlated with bushel weight, except in a few specific instances. Zavitz (9) concluded that the weight per measured bushel was a very poor criterion for determining the relative value of different varieties of oats. He contended that weight per bushel was influenced more by the length than by the quality of the oat grains of different varieties. A long thin-hulled oat of high quality was found invariably to weigh less per bushel than a short plump thick hulled variety which was of considerably less value for feeding purposes. Other workers have indicated varying degrees of importance in weight per bushel as a measure of quality in oats.

Love (4) found a difference of nearly 100% in the weight per 100 grains as determined for a number of different varieties. However, no correlation was found between weight per 100 grains and hull percentage. Surface and Zinn (8) suggested that the weight of a given number of primary kernels was a more reliable measure of quality than the weight of a given volume of grain (test weight). They could not, however, find a significant correlation between weight of a thousand grains and percentage of hull.

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[1]Contribution from the Farm Crops Subsection of the Iowa Agricultural Experiment Station, Ames, Iowa. Journal paper J-1088. Project 741. Received for publication February 6, 1943.

[2]Research Assistant. The author acknowledges thanks to L. C. Burnett and I. J. Johnson under whose direction this study was made and to the Quaker Oats Company for grant of funds for this study.

[3]Numbers in parenthesis refer to "Literature Cited", p. 539.

Test weight and yield were both found to be strongly negatively correlated with coefficient of crown rust infection by Murphy, et al. (6). Stoa, *et al.* (7) found all rust-infested varieties to average high in hull percentage. They also found early oats, as a group, to have a relatively lower percentage of hull than midseason varieties.

Dehulling oats by hand to determine hull percentage must be done on a relatively small sample. Garber and Arny (2) made a study of the size of sample to be used and concluded that, in general, a 200-grain sample carefully taken gave sufficiently accurate results for all ordinary purposes. Love (4) considered a 100-grain sample large enough for accurate determinations. Other workers have used samples within the above limits for determining hull percentage.

For information on the method of milling oats, descriptions and definitions of related products, composition, and uses of the oat foods, feed materials, and industrial products, the reader is referred to the work of Brownlee and Gunderson (1).

MATERIAL AND METHODS

The oat samples used in this study were obtained from variety trials grown in 12 Iowa counties and from the experimental nurseries grown at Ames, Kanawha, and Cherokee, Iowa, in 1941 and 1942. A 10-gram sample from each replication was separated by hand into primary kernels and secondary kernels and the percentage bosom kernels was calculated on a weight basis. One hundred primary and 100 secondary kernels were counted out and weighed. These 100-kernel samples were then dehulled and the percentage of hull calculated.

EXPERIMENTAL RESULTS

VARIETY TRIALS

The 1941 oat crop in Iowa was quite generally a very poor one. Crown rust, *Puccinia coronata avenae* (Corda) Eriks. and Hern., was present in epiphytotic proportions throughout most of the state and especially in the major oat-growing area of northwestern Iowa. Consequently, varieties susceptible to crown rust infection were materially reduced in yield and quality, while the resistant varieties were nearly normal in performance. Thus, the data obtained in 1941 were grouped into two classes, according to the crown rust resistance or susceptibility of the varieties.

The oat crop in 1942 was much better in yield and quality than that of the previous year. Crown rust was much less prevalent, occurred late in the season, and caused only slight damage. Therefore, the results probably are more representative, since quality factors were not confounded with crown rust reaction. The data obtained from the 1941 and 1942 variety trials are summarized in Table 1.

The analysis of variance for hull percentage, kernel weight, ratio of primary to secondary kernels, and yield was calculated for each location in both years and the varietal differences were found to be statistically significant in all but a few instances. Figures given for bushel weight are for single determinations only and thus a statistical analysis of their significance was not possible. The data for percentage double oats was not tested statistically because of the large number of zero values within replications of a variety.

TABLE I.—*Hull percentage, weight of 100 kernels, ratio of primary to secondary kernels, percentage of bosom kernels, test weight, and yield in oat variety trials grown in 1941 and 1942.*

Character	Marion	Tama	Boone	C.I. 3350	Hancock	Ia. 103 (Albion)	Ia. 105 (Richland)	Vanguard	Gopher	Columbia	Mean	Level of significance .05	Level of significance .01
1941 (10 Tests)													
Hull %, primary kernels	27.7	32.1	30.6	27.2	27.4	31.1	33.8	32.1	33.1	31.1	30.6	1.3	1.7
Hull %, secondary kernels	23.4	24.9	23.8	22.5	23.9	26.6	28.4	26.5	28.3	27.4	25.6	1.1	1.4
Weight of 100 primary kernels, grams	2.67	2.56	2.68	2.63	2.41	1.92	1.80	2.29	1.99	2.17	2.31	0.11	0.14
Weight of 100 secondary kernels, grams	1.45	1.46	1.48	1.42	1.27	1.11	1.07	1.36	1.20	1.19	1.30	0.07	0.09
Ratio of P/S kernels	2.40	2.09	2.14	2.52	2.74	1.86	2.04	1.83	1.85	2.27	2.17	0.30	0.39
Bosom oats, %	0.2	5.2	4.1	0.4	0.5	4.0	5.6	7.7	4.6	0.1	3.2	—	—
Test weight, lbs.	30.3	29.0	29.3	29.6	28.6	24.6	24.4	23.4	23.9	28.2	27.1	—	—
Yield, bu. per acre	57.5	56.9	56.6	55.3	48.2	43.6	42.1	40.2	39.5	37.6	47.9	7.0	9.2

1942 (12 Tests)

Character	Marion	Boone	Tama	Sac	Hancock	Ia. 105	Vanguard	Gopher	Columbia	Mean	Level of significance .05	Level of significance .01
Hull %, primary kernels	25.6	27.9	28.9	25.3	24.7	29.5	30.2	28.8	26.4	27.5	1.2	1.6
Hull %, secondary kernels	20.7	20.9	22.2	19.6	21.4	24.1	24.4	23.7	22.6	22.2	0.9	1.2
Weight of 100 primary kernels	2.98	3.03	2.84	3.27	2.74	2.18	2.74	2.47	2.78	2.78	0.12	0.16
Weight of 100 secondary kernels	1.65	1.67	1.65	1.84	1.38	1.34	1.56	1.50	1.56	1.57	0.07	0.09
Ratio of P/S kernels	4.04	2.90	2.45	4.61	5.50	2.34	2.91	2.69	3.06	3.39	0.56	0.77
Bosom oats, %	0.3	1.4	1.4	0.6	0.4	1.2	4.6	1.0	0.1	1.2	—	—
Test weight, lbs.	30.6	32.2	31.2	32.5	30.6	27.9	25.4	28.4	28.3	29.7	—	—
Yield, bu. per acre	60.9	62.3	67.9	58.4	55.4	53.4	58.6	56.9	50.8	58.3	5.9	7.8

From the combined analysis of variance it was found that for all characters the variety and location mean squares were highly significant when tested against the variety × location interaction. Likewise, the variety × location interaction was highly significant in every case when tested against the pooled error term. The highly significant interaction of variety × location would have been anticipated in 1941 because crown rust infection was shown to have a pronounced effect on the characters studied. Crown rust infection was not equally severe in all locations and hence differential response of varieties in the locations studied would naturally follow. In 1942, when crown rust was a relatively minor factor in varietal performance, highly significant variety × location interactions were also obtained, suggesting that the nine varieties responded in a differential way to the environmental conditions represented in the 12 locations. In respect to such factors as hull percentage, kernel weight, and ratio of primary to secondary kernels, the results would indicate that the choice of varieties for milling purposes in the different locations may be highly important.

The miller is primarily interested in how many bushels of oats will be needed to produce a barrel of millable groats. In view of this fact the hull percentage determinations are perhaps the most important of the various factors studied. Other factors have varying amounts of influence on the final yield of groats, but in a less direct sense. The primary kernels are largely used for milling purposes and as shown in this study average 4 to 6% higher in hull percentage than the secondary kernels. This offers a point for speculation. From the millers' standpoint a plump, heavy, primary kernel is generally thought of as a desirable character in an oat variety. On the other hand, varieties such as Boone, Tama, and many of the Bond hybrid selections produce a plump blocky secondary kernel of low hull percentage which may have value from a milling standpoint. Many blocky secondaries of this type are graded as "stubs" at the mill and are utilized for milling purposes. The addition of an appreciable amount of such secondary kernels to the milling oats would seem to be of advantage from the standpoint of increasing the proportion of millable oats per bushel and in reducing the hull percentage of the milling oats.

The evaluation of the significance of the ratio of primary to secondary kernels also presents a problem. In general, a high ratio should indicate a relatively large proportion of plump heavy primary kernels desirable for milling purposes. However, a variety with a low ratio might actually yield a larger proportion of milling oats if the low ratio was due to plump blocky secondary kernels. Apparently, the size and shape of the kernels should be considered in addition to the weight ratio in obtaining an accurate estimate of the value of an oat variety for milling purposes.

Double or "bosom" kernels in which the lemma of the primary grain completely or almost completely envelopes the secondary grain are undesirable as milling oats. This condition results in poor development of both the primary and secondary groats and such kernels are separated out at the mill and not used for milling purposes.

Vanguard was consistently high in percentage of double oats. Iowa 105, Tama, Gopher, and Boone were also undesirable in this respect. Samples of these varieties contained as high as 28% double kernels in certain locations and hence would give very poor milling yields. Marion, Hancock, C.I. 3350, and Sac had very few bosom kernels, and Columbia was almost entirely free of them.

In view of the fact that hull percentage is of major importance as a quality criterion in oats, correlation coefficients were calculated between it and several other factors. The correlation coefficients of hull percentage with yield, bushel weight, and kernel weight for both seasons are given in Table 2. The coefficients were calculated from the mean values from the 10 varieties in the 1941 variety trials and the 25 varieties and selections from the experimental nurseries at Ames, Kanawha, and Cherokee in 1942.

TABLE 2.—*Correlation coefficients of hull percentage with yield, bushel weight, and kernel weight.*

Characters correlated with hull percentage	Hull percentage					
	1941			1942		
	Primary kernels	Secondary kernels	Av.	Primary kernels	Secondary kernels	Av.
Yield	–.530	–.849**	–.706*	.005	–.005	.006
Bushel weight	–.733*	–.820**	–.803**	–.689**	–.769**	–.747**
Weight of primary kernels	–.674*	———	———	–.554**	———	———
Weight of secondary kernels	———	–.795**	———	———	–.668**	———
Av. weight of kernels	———	———	–.767**	———	———	–.650**

*r value exceeds the 5% point.
**r value exceeds the 1% point.

In the rust year of 1941 yield and hull percentage tended to be significantly negatively correlated, while in the more normal 1942 season no relationship was found between these two factors. This difference can be explained on the basis that in 1941 yield data were actually a combined expression of both the inherent yielding ability and the rust reaction of the varieties. A negative relationship (r = .706) between the yield and hull percentage was obtained because the weight of hulls is not influenced by rust infection and the plumpness of the groat is greatly reduced. In the 1942 yield data, which are not confounded with rust reaction, no correlation (r = .006) between yield and hull percentage was found. Under ordinary conditions of growth there would seem to be no reason to expect a high-yielding variety necessarily to be high or low in hull percentage. Significant negative correlations of hull percentage with bushel weight and kernel weight were obtained in both seasons.

While these indications of hull percentage are consistent in most cases, definite varietal differences are shown in the data. For example, Boone and Tama are among the better varieties in bushel weight

and weight of kernels. They should then be among the varieties low in hull percentage, but the data show them to be medium to high in this respect. Love, *et al.* (5) and Hayes, *et al.* (3) have similarly reported that large heavy seeds do not always indicate a low percentage of hull. Such examples substantiate hull percentage as a distinct variety characteristic and emphasize the value of the actual hull percentage determinations.

In making any conclusions as to the relative merit of the different varieties for milling purposes one should then place varying emphasis on the factors studied. Hull percentage should be given strongest consideration followed by percentage bosom kernels. Weight of primary kernels, ratio of primary to secondary kernels, and bushel weight should be used more or less as substantiating evidence. As weight per bushel is one of the points taken into consideration in the grading of oats it must be considered. It is a fairly good basis for judging quality in oats, even though certain varietal exceptions make it less dependable than hull percentage.

An evaluation of the varieties in the trials on this basis would indicate that Markton-Rainbow strains (Marion, Hancock, and C.I. 3350) and Sac to be the best varieties for milling purposes. They are low in hull percentage, produce negligible amounts of bosom kernels, give high kernel and bushel weights, and have a high ratio of primary to secondary kernels. While no data were obtained on the carotinoid pigment content of the different varieties, the light color of the groats which are desired by the milling trade were very noticeable in the Markton-Rainbow strains. Relatively high hull percentages, an appreciable amount of bosom kernels, and a dark yellow-colored groat make Boone and Tama less desirable varieties. However, they are generally equal to or better than most of the older varieties, especially in a season when crown rust is a factor. Columbia appears to be a satisfactory milling variety when crown rust infection is not serious. It gave low hull percentages in the 1942 season and the almost complete absence of double kernels was noticeable in both seasons. Gopher, Iowa 103, Iowa 105, and Vanguard were less desirable in essentially that order. All were high in hull percentage and bosom kernels and low in kernel and bushel weight.

EXPERIMENTAL SELECTIONS

In 1941 the 14 experimental selections studied consisted mainly of selections from crosses of Bond with Iogold, Anthony, and Selection D69. The 16 experimental selections studied in 1942 were nearly all from crosses of D69 with Bond.

A comparison of the experimental selections with Marion for hull percentage and weight of kernels is summarized in Table 3. In both seasons the majority of the selections were equal or superior to Marion in weight of primary kernels and tended to produce somewhat heavier secondary kernels. The experimental selections in 1941 were mostly equal to or but slightly lower than Marion in hull percentage, while those in 1942 were somewhat higher than Marion in hull percentage.

TABLE 3.—*Comparison of experimental selections with Marion as 100 for hull percentage and weight of kernels.*

Character	Frequency distribution in percentage of Marion														Level of significance	
	70	75	80	85	90	95	100	105	110	115	120	125	130	135	0.05	0.01
							1941									
Hull %, primary kernels	–	–	–	–	1	2	8	2	–	1	–	–	–	–	2.3	3.1
Hull %, secondary kernels	–	–	–	–	2	8	2	2	–	–	–	–	–	–	2.4	3.2
Weight of primary kernels	–	–	–	1	–	–	1	6	3	1	2	–	–	–	2.8	3.7
Weight of secondary kernels	–	–	1	–	–	–	–	–	2	4	5	–	–	2	3.9	5.2
							1942									
Hull %, primary kernels	–	–	–	–	–	3	–	4	7	2	–	–	–	–	3.8	5.1
Hull %, secondary kernels	–	–	–	–	1	2	–	2	10	1	–	–	–	–	5.0	6.6
Weight of primary kernels	–	–	–	–	1	3	6	3	1	1	1	–	–	–	4.8	6.4
Weight of secondary kernels	–	–	–	1	–	–	2	5	4	1	–	2	1	–	10.0	13.4

These results would indicate that, in general, selections may be made from crosses in which Bond is one of the parents that are satisfactory for milling purposes. These results are of importance because of the widespread use of the variety Bond in crosses as a source of resistance to crown rust.

SUMMARY

Oat varieties included in variety trials and selections from the experimental nurseries grown at Ames, Kanawha, and Cherokee, Iowa, were used in 1941 and 1942 in a study of differential qualities that might have a bearing on their use for milling purposes.

Hull percentage and percentage of bosom kernels were found to be the most accurate measures of milling quality in oats. Kernel weight, ratio of primary to secondary kernels, and bushel weight were indicated to be of value as substantiating criteria of quality.

The hull percentage of the primary kernels was found to average 4 to 6 higher than that of the secondary kernels. A broader, heavier kernel base, the attached rachilla of the secondary kernel, and remnant awns probably account for the increased hull percentage of the primary kernels.

Among the varieties in the trials, the Markton-Rainbow strains (Marion, Hancock, and C.I. 3350) and Sac appeared to be superior for milling purposes. They were low in hull percentage, produced negligible amounts of bosom kernels, gave high kernel and bushel

weights, and had a high ratio by weight of primary to secondary kernels. Among the experimental varieties and selections, largely from crosses with Bond, the majority were equal or superior to Marion in hull percentage, kernel weight, percentage of bosom oats, and weight per bushel. These selections combine in a high degree resistance to the major oat diseases and are outstanding also in yielding ability.

Highly significant differences were obtained for varieties, locations, and the variety × location interaction of each character studied.

Significant negative correlations were obtained between hull percentage and yield, bushel weight, and kernel weight in 1941 when crown rust infection materially affected varietal performance. In 1942, hull percentage was not correlated with yield but was significantly correlated with bushel weight and kernel weight.

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NOTES

HARVESTING SWEET CLOVER SEED WITH A CORN BINDER

HARVESTING seed of the large, late strains of white sweet clover has always been difficult. However, both because they yield more and especially because they furnish pasture some weeks later in the summer, when pastures are short, these large late strains are much more valuable for pasture than ordinary commercial white sweet clover which has come to be largely of the Grundy County type. Repeated attempts at Ohio State University and on other farms to harvest this seed by direct combining have failed. The seed crop does not ripen at one time, and shatters soon after it ripens. While the plant is green, the combine clogs with green material, and much of the seed saved is green and requires careful drying. When the stalks are dry enough for combining, much, or often all, of the seed has shattered.

Doctor J. B. Park of the Department of Agronomy of the Ohio Agricultural Experiment Station introduced in 1935 a valuable large late strain of sweet clover under the name Evergreen. Despite its value, harvesting the seed crop had failed to the extent that only a small amount of seed of the strain was available in 1940. In order to increase this strain as rapidly and surely as possible, it was sown with a hand garden seeder in rows marked out with a corn planter and cultivated throughout the first season. The next year this sweet clover averaged 7 feet tall and harvesting promised to be a serious problem.

Since this sweet clover was in 40-inch rows, we tried using a corn binder to harvest it, cutting it in the morning before the dew was off. The result was an extremely satisfactory sweet clover seed harvest. The coarse, heavy, material was tied in neat, tight, bundles which later threshed an exceptional yield of seed.

The standard corn binder cannot be used to harvest broadcast sweet clover because the grain wheel extends into the uncut sweet clover, riding it down and tangling the wheel. In order to make corn binder harvesting of sweet clover more feasible, the senior author suggested that the right hand gathering point of the binder be extended forward and out to cut a sufficiently wide swath to clear the land wheel of the binder. Doing this would also make for more rapid cutting since a wider swath would be taken.

The junior author designed and made the attachment shown in Fig. 1. It consisted of strap iron and extended the gathering point of the binder about 2 feet forward and 8 inches to the right. The iron was braced to the main frame at several points and finally carried around the grain wheel. This device was made in about 2 hours. It cut a broadcast field of Evergreen sweet clover very satisfactorily in 1942.

Another plan to make it possible to use the corn binder for harvesting sweet clover seed was tried in 1942. Sweet clover was sown in wheat with the grass seed attachment on a grain drill, sowing sweet clover from every fourth spout of the drill. Red clover was sown from the other three spouts. Although, due to seeding conditions,

we obtained a rather thin stand of sweet clover, there is no apparent reason why this method of seeding sweet clover should not be successful. Such a seeding could readily be harvested with a corn binder. The red clover was sown in the intervening rows in order to avoid leaving the ground bare during the fall of the seeding year and the early part of the second year. The red clover does not interfere with seed production of the sweet clover, but does improve the soil and reduce erosion materially.

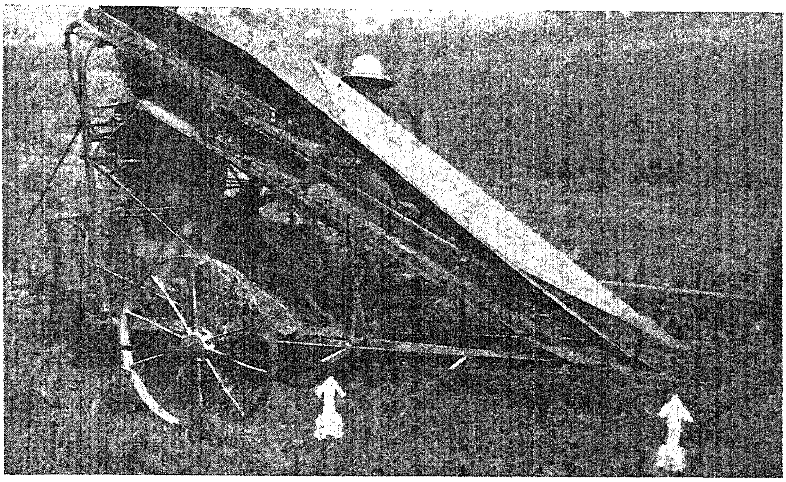

FIG. 1.—Corn binder equipped for cutting sweet clover.

W. G. Weigle of the Marsh Foundation Farms, Van Wert, Ohio, advises that the common method of harvesting sweet clover seed in northwestern Ohio was used successfully on Evergreen sweet clover in 1942. This method is to set a grain binder as high as possible on the wheels, take off the binding trip so that the needle will not function, and tie up the bundle carrier, allowing the binder to deliver the sweet clover in a continuous windrow on the outside of the machine. This windrow will lie on top of the stubble. As soon as it is dry a "straight-through" combine is used, cutting off the stubble under the windrow of sweet clover. This method is preferable to using a pickup attachment, which shatters some of the seed.

Whenever any type of binder is used to harvest sweet clover seed, the work should be done early in the morning while the dew is still on, or, if there is a large amount of work to do, at night. Working in the dry part of the day will inevitably result in a total loss of the best quality seed.—C. J. WILLARD, *Department of Agronomy, and* C. B. RICHEY, *Department of Agricultural Engineering, Ohio State University, Columbus, Ohio.*

FORAGE CROP NURSERY MOWER

LABOR at harvest time is the chief problem in the testing of forage crops by the rod-row method. The general practice of cutting by hand is not only time-consuming but often leaves a ragged

FIG. 1.—Mower operating in 36-inch rows of crested wheatgrass.

stubble. When an accurate forage weight is desired, it is important that all rows be cut at a uniform height from the ground. There is need for a motor-powered cutter for harvesting nursery rows of forage crops that is inexpensive, light in weight, easily manipulated, and narrow enough to cut a single row without disturbing the adjacent rows.

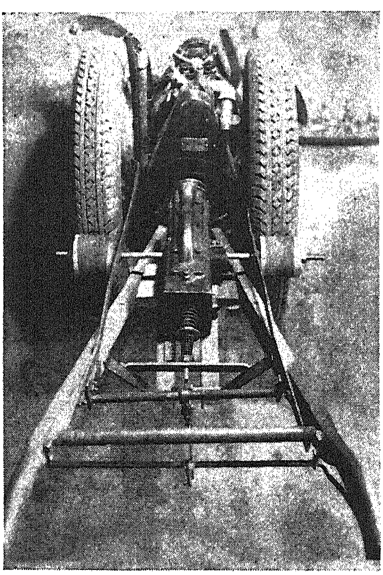

FIG. 2.—Drive unit on nursery mower.

A machine (Fig. 1) built in the spring of 1939 and used at the Montana Agricultural Experiment Station for the past four seasons consists of a used 1 h.p., four cycle, gasoline (washing machine) motor mounted on a frame built of angle iron (discarded bed rails) and set between two 3.75 × 18-inch rubber-tired wheels, identical to those used by the Masters Planter Company on their chemical distributor. Bicycle wheels with balloon tires could be substituted for the rubber-tired wheels described above.

The motive power is transmitted to the sickle-bar by means of a system of different-sized "V" pulleys and belt which make it possible to regulate the ratio of speed and power needed to cut different species. A mowing machine knife head, pitman rod, and pitman fly-wheel supply mower action to a short section of a discarded grain binder sickle-bar. The small guards and serrated sections of the grain binder sickle-bar were selected because of decreased weight and more efficient cutting per unit length of bar.

Traction is obtained by means of a friction drive (Fig. 2). The speed reduction gears consist of enclosed spiral gears obtained from a discarded cream separator. The friction drive pulleys were covered with sponge rubber. They are "put in gear" or, in other words, contact the tires as a result of a control attached to the handle.

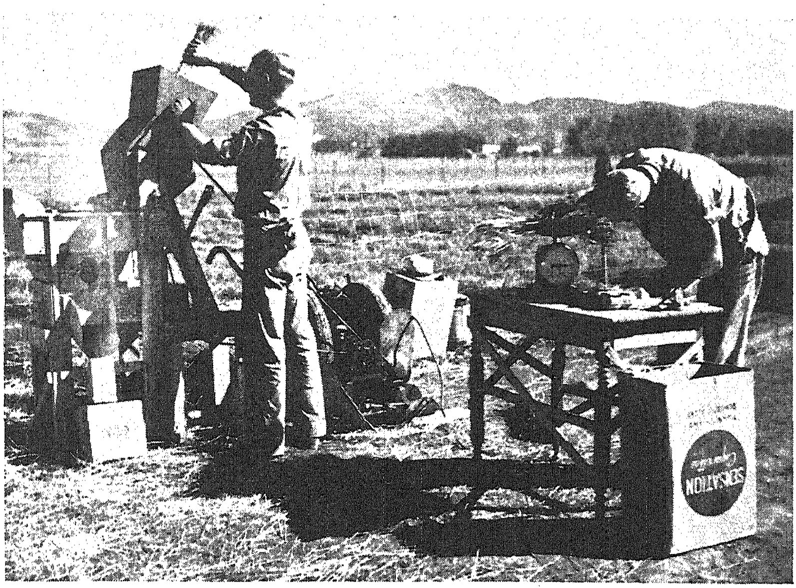

FIG. 3.—Threshing individual plants in the field. Power supplied by motor in nursery mower.

The "V" belt pulleys, "V" belt, and wheels are the only parts which cannot be obtained from a junk dealer or used machinery shop.

Without a reel, a mower of this kind has a tendency to miss the last plant on the end of a row. This disadvantage can be overcome by having an assistant pull the plant towards the sickle with an ordinary grass hook. Two men can cut and gather the forage on five rod rows every minute.

The engine may be used as a portable source of motor power to drive other nursery equipment by disconnecting the belt from the cutting unit and re-attaching to drive pulleys on other machines. The motor was used to power a small nursery thresher (Fig. 3).

Detailed photographs which would aid in the construction of a mower of this type can be secured from the Agronomy Department,

Montana State College, Bozeman, Mont.—L. A. CLARK, *Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, cooperating with the Montana Agricultural Experiment Station, Bozeman, Mont.*

GROWTH AND COMPOSITION OF CURLED MALLOW, *MALVA CRISPA*

WITHIN recent years a number of inquiries have been received concerning the possible forage value of a certain plant belonging to the mallow family. This plant has been claimed to be a hybrid between the hollyhock, *Althaea rosea* Cav., and the common mallow or "cheeses", *Malva rotundifolia* L., or some other plant, supposedly a "secret". It has also been exploited as a "new crop" with marvelous possibilities as a forage plant especially for goats and dairy cows. Whenever specimens of the plant in question were available for determination, they proved to be the curled mallow, *Malva crispa* L., an adventive from Europe. The curled mallow has been in the northeastern United States for a long time, having at times been grown for the ornamental effect of its curled or ruffled leaves. Occasionally it escapes and becomes a weed.

Because of the interest in the curled mallow and the claims made for it, it was decided to obtain some data regarding its habit of growth, yield, and composition. Seed was obtained from two sources in New York State, from samples of plants submitted for determination to the senior author in 1941. Part of the seed was planted in flats in a greenhouse and the seedlings were transplanted to the field May 20, 1942, when they were about 4 inches high. The rest of the seed was planted directly in the field with a hand seed drill May 1, 1942. The field was located on a well-drained sandy loam at Ithaca, N. Y. A commercial fertilizer (5–10–5) was drilled on the soil at the rates of 250 pounds, and 750 pounds per acre, 6 days before the seed was planted.

The plants were set 15 inches apart in the rows which were 3 feet apart. Those from the drilled seed were thinned out to the same distance. The plants were cultivated twice with a horse cultivator and at the same time they were hoed and weeded within the rows.

The plants made a rapid growth and reached maturity in the transplants about 20 days before those grown from seed sown directly in the field. The final total growth, both in size and weight, was very similar for the plants whether they came from drilled seed or greenhouse transplants. The general appearance, vigor, and total yield of the plants showed no significant difference on the soil with light or heavy application of fertilizer. Fig. 1 shows the general habit of growth of the curled mallow plants as they appeared on August 25. These plants are about 8 feet high.

Curled mallow is a rapid grower with a main stem or leader bearing numerous short, leafy, axillary branches with numerous small flowers that set seed in abundance. The seed do not all ripen at the same time and some may shatter while new flowers are still appearing. When

the plants were cut with a corn knife and shocked in an upright position, the leaves, lateral branches, and seeds dried in good condition. The main stems dry rather slowly and may mold in poor drying weather. The crop was harvested at one cutting. By cutting the plants about 8 inches above the base when they are about 3 feet high, a second or even a third cutting may be made from the new growth from lateral buds. Such treatment would reduce the relative bulk of the fibrous matter of the main stem and possibly also increase the total yield of the crop.

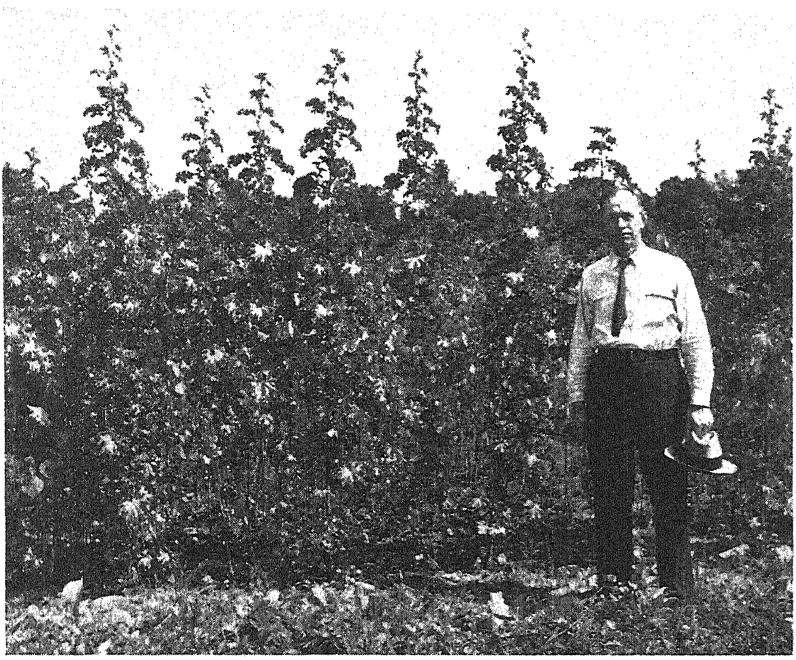

FIG. 1.—Curled mallow plants 12 weeks after the seed was planted.

The total yield of green weight was estimated to be from 9 to 11 tons per acre. The dry weight varied from 2 to 3 tons per acre. These estimations are based on duplicate lots of 10 plants from field-sown seed, each taken at random in the field on August 21. The summer of 1942 was a favorable growing season with adequate rainfall. In a dryer summer the yields might not be as large.

Two plants harvested August 21 were analyzed for protein, fats, crude fiber, ash, and nitrogen-free extract. The results of these analyses are recorded in Table 1 and show that the plants as a whole, on a dry-weight basis, contain from 19 to 20% protein and about 24% crude fiber. In protein content the curled mallow exceeds the best grade of leafy alfalfa hay which analyses 16.5% protein and 22.6% fiber. Most alfalfa hay contains only about 14% protein.

The curled mallow suggests a possible source of high protein

TABLE 1.—*Composition of Malva crispa.*

Part of plant	Dry weight in grams air-dry basis	Percentage composition					
		Total dry matter	Protein	Fat	Crude fiber	Nitrogen free extract	Ash
		Plant I					
Leaves*	224	93.67	22.82	3.68	18.57	38.97	9.63
Stems†	66	92.41	6.38	1.15	42.29	37.41	5.18
Whole plant	290	93.38	19.08	3.10	23.97	38.61	8.62
		Plant II					
Leaves	252	93.27	22.35	3.73	19.68	37.19	10.31
Stems	43	94.16	6.25	1.26	48.24	33.45	4.96
Whole plant	295	93.40	20.01	3.37	23.84	36.65	9.53
		Average Composition of Plant					
Air-dry basis	—	93.43	19.53	3.24	24.00	37.60	9.06
Fresh basis	—	18.12	3.79	0.63	4.66	7.29	1.75

*Leaves include the primary leaves and also the short, leafy side branches with flowers and partly formed seed clusters.
†Stems include only the main stem or leader.

forage or fodder worth further investigation. When grown as an annual cultivated crop, it may yield 3 tons of dry matter on an acre, containing approximately 20% protein.—W. C. MUENSCHER, *Department of Botany*, and J. K. LOOSLI, *Department of Animal Husbandry, Cornell University, Ithaca, N. Y.*

AGRONOMIC AFFAIRS

SOIL SCIENCE SOCIETY PROCEEDINGS

AS this number of the JOURNAL goes to press, volume 7 of the PROCEEDINGS of the Soil Science Society of America has been completed and is going into the mails. It contains the papers presented at the meeting of the Society held in St. Louis in November, 1942, and in size is almost an exact duplicate of volume 6. Orders for volume 7 of the PROCEEDINGS should be placed with Doctor G. G. Pohlman, Secretary-Treasurer of the Soil Science Society at the University of West Virginia, Morgantown, W. Va.

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RESPONSE OF GEOGRAPHICAL STRAINS OF GRASSES TO LOW TEMPERATURES[1]

GEORGE A. ROGLER[2]

OUT of approximately 1,500 accessions of grasses studied at the Northern Great Plains Field Station, Mandan, N. Dak., from 1936 to 1941, 40% failed to survive the extreme climatic conditions. The majority of these grasses were species and strains of importance occurring naturally within some portion of the Great Plains region. They failed to survive primarily because of winter injury. This fact emphasizes the need for more studies pertaining to adaptation before particular strains or species are recommended for widespread use.

These investigations were carried on in the field at Mandan, N. Dak., and in the greenhouse and low temperature research laboratory at the University of Minnesota. The purpose of this study was to obtain information on the resistance to low temperatures of seedlings and mature plants of geographical strains of grasses.

REVIEW OF LITERATURE

Since this study takes up the effect of cold temperature on geographical strains of grasses, it seems desirable to review some of the literature pertaining to the general distribution of geographical strains of plants and their variation in nature, as well as literature bearing more directly on freezing studies.

[1]Field data were obtained through cooperative investigations of the Division of Forage Crops and Diseases, the Division of Dry Land Agriculture, Bureau of Plant Industry, Agricultural Research Administration, and the Nursery Division, Soil Conservation Service, U. S. Dept. of Agriculture. Laboratory data were obtained through cooperative investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration U. S. Dept. of Agriculture, and Division of Agronomy and Plant Genetics, University of Minnesota. Received for publication February 6, 1943.

[2]Associate Agronomist, Division of Forage Crops and Diseases and the Division of Dry Land Agriculture, Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture, Mandan, N. Dak. The writer wishes to express his appreciation for helpful advice to Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics, University of Minnesota, and to the University of Minnesota for the use of the greenhouse and controlled temperature chambers.

Arny (2)[3] found that strains of medium red clover produced in France, Chile, and Italy winterkilled 81%, 89.5%, and 93.9%, respectively, during the winter of 1922–23 at St. Paul, Minn. Strains from northern Europe killed much less, and those from north central and north inter-mountain states in this country gave low percentage of winterkilling.

Law and Anderson (6), in working with *Andropogon furcatus* Muhl., point out that this species exhibits a wide range of adaptation to many soil types and to a variety of climatic conditions. Strains from Nebraska, Kansas, and Oklahoma grown at Manhattan, Kans., indicate definite ecotypes which have developed as a result of natural selection over a long period of time. In general, the northern plants were earlier, smaller, and less leafy than those of southern origin, while the plants from Kansas were intermediate in these characters. The heading date of the Nebraska plants was 21 days earlier than that of the Kansas plants, while Oklahoma plants headed 47 days later than those from Kansas.

It will be brought out in the discussion that all warm temperature species studied tend to become dormant in the fall regardless of how high or optimum the temperature is maintained, while the cool temperature species do not show this tendency. Shepherd (11) has shown that *Andropogon furcatus*, *Bouteloua curtipendula* (Michx.) Torr., and *B. gracilis* (H.B.K.) Lag. remain dormant for the greater part of the winter and will not grow though given an artificial climate with optimums of temperature and light duration. If the rest period is broken by freezing, vegetative growth will be produced. He pointed out also that *Agropyron smithii* Rydb. does not become dormant when transplanted to the greenhouse in the fall.

Studies of the nature of frost resistance in plants are voluminous. Recent reviews have been made by Harvey (5), Levitt and Scarth (8), and Levitt (7). Excellent early reviews were made by Abbe (1), Chandler (3), and Harvey (4).

Previous investigations by many workers on methods of artificially freezing various species were used as a working guide in setting up the related portion of the present study.

Shultz (10) exposed 66 clonal lines of 2-year selfed plants of *Dactylis glomerata* L. that had been grown in the greenhouse to a 12-day hardening-off period at 2° C. They were then frozen at –10° C for 24 hours and thawed at 2° C for 40 hours before being returned to the greenhouse. The analysis of the results showed a highly significant difference in the reaction of various clones to artificial freezing even though all clones had originated from plants that were relatively winterhardy in the field. Clones from commercial plants unselected for winterhardiness were frozen under the same conditions. These clones as a group were more severely injured by freezing than the selected selfed clones. In testing the association between field hardiness of the selfed clones and their reaction to artificial freezing, he found that no correlation existed. In his field hardiness tests winterhardy parents showed a tendency to produce winterhardy selfed progenies. Strains from Germany, Wales, and New Zealand were also tested and found to be low in winterhardiness, while those from local collections and from Canada ranked high in winterhardiness.

MATERIAL AND METHODS

The species used in this study are grouped into two broad classifications based on the period of maximum vegetative growth. These groups are called "cool

[3]Figures in parenthesis refer to "Literature Cited", p. 559.

temperature species" and "warm temperature species". Cool temperature species are those which make their maximum vegetative growth during the spring and fall with a lesser amount of growth during the hot part of the summer. These species start growth very quickly after the ground thaws out in the spring and if moisture conditions are favorable in the fall they continue growth until late in the season. The warm temperature species make their maximum growth during the summer season and at Mandan, N. Dak., start their spring growth approximately 3 weeks after the cool temperature species. They cease growing with the advent of the first hard frost in the fall.

The cool temperature species used in the study of reaction to artificial freezing were *Agropyron cristatum* (L.) Gaertn., *A. smithii* Rydb., and *Bromus inermis* Leyss. Three geographical strains of each species were used, and in addition, the standard strain of *A. cristatum* was used as a check.

All species are of major importance in the Northern Plains. All are highly cross-pollinated and show wide variability. No reports of winter injury to establish stands of any of these species have been made. *Agropyron cristatum* and *B. inermis* have been grown successfully as far north as Whitehorse, Yukon, where temperatures as low as -60° F have been recorded. All strains of *A. cristatum* used in this study originated in the north, except No. 1227, which was grown in Nebraska and is of unknown origin. These strains were all of the commercial standard type, except No. 96–24 and No. 23 Fairway. No. 96–24 is a large-seeded, awnless, standard-type strain, which produces larger, more vigorous-growing seedlings than the other strains studied. The Fairway strain is distinctly different in growth character and has a somatic chromosome number of 14, while the standard type has a somatic number of 28 chromosomes (9). Both the seed and seedlings of Fairway are smaller than those of the standard variety.

Bromegrass strain No. 1253 has been grown in Nebraska and northern Kansas for approximately 40 years. The Parkland strain was developed at the University of Saskatchewan (12) and No. 1250 was a commercial strain from North Dakota. All *A. smithii* strains were bulk collections.

Warm temperature species used in the study of reaction to artificial freezing were *Andropogon furcatus* Muhl., *Bouteloua gracilis* (H.B.K.) Lag., *B. curtipendula* (Michx.) Torr., and *Panicum virgatum L.* Three geographical bulk-collected strains of each species were included in the study. These warm temperature species are all native grasses of major importance and occur over a wide geographical range. They are also cross pollinated and widely variable.

At the beginning of the grass improvement program at Mandan, N. Dak., in the spring of 1937, seed of a large number of geographical strains of the major Northern Plains species was assembled and planted in the greenhouse. Individual plants were then transplanted to the field. The individual plants were established on very uniform soil and spaced 42 inches apart in each direction with 40 plants to a row. Each spring after growth had started, careful counts were made of the number of plants that were completely killed and of those that were partially killed. The partially killed plants had suffered winter injury but were not completely dead.

In the field studies it was assumed that differences in survival were due primarily to cold injury. No severe droughts occurred during the period and since the plants were spaced 42 inches apart in each direction, moisture conditions were such that plants could make maximum growth. This being the case, danger of injury from dessication was slight. The minimum temperature during the 4-year period was -34° F on February 14, 1939. The greatest snowfall for any one

month was 12.9 inches in February 1938. Snow cover played some part in protecting the plants. In most cases the covering was light and uniformly distributed over the entire area.

Under conditions at Mandan, survival of spaced plants of the species in this study might, in some cases, be somewhat different from survival in solid stand seedings. Spaced plants do not offer as much mutual protection as plants in solid seedings. However, the more plentiful soil moisture in spaced plantings and consequent increase in plant vigor tend to offset this lack of mutual protection. Observations on the survival of plants in solid seedings indicate that survival data from spaced plants are a good index of the survival that may be expected from solid seedings of the same strains. For the purposes of this study the use of spaced plants made it possible to determine actual percentages of killing.

On August 25, 1941 two individual plants from each geographical strain to be frozen artificially were dug and divided clonally and established in the greenhouse. After a period of hardening for 7 days at 2° to 4° C, these clones were frozen at different ages and at various temperatures, as will be brought out in the discussion.

Seed of three strains each of cool temperature species and four warm temperature species was planted on August 27, 1941, and seedlings transplanted to flats on September 24. Twelve replications each of the warm temperature and cool temperature species, respectively, were transplanted with one flat containing a replication. All geographical strains of warm temperature species were included within each of the 12 flats of warm temperature species. In like manner all strains of cool temperature species were represented within each of 12 flats of cool temperature species. Commercial *Agropyron cristatum* was used as a check in all cases with both the warm and cool temperature species. Each strain was represented by a row of 10 seedlings. The rows were randomized within each flat and were transplanted approximately 2 inches apart. Each flat of cool temperature species contained 12 rows including three check rows, and each flat of warm temperature species contained 14 rows including two checks. Another series of 12 replications of both warm and cool temperature species was seeded on September 24 and handled as previously described. A day length of approximately 14 hours was maintained in the greenhouse at all times by using light from incandescent lamps as a supplement to natural daylight.

All seedlings were hardened for 7 days at 2° to 4° C before being subjected to freezing temperatures. Two 200-watt incandescent lamps were kept burning in the hardening chamber to keep the plants from becoming etiolated. After freezing, the flats of seedlings were allowed to thaw for 48 hours at 2° to 4° C before being returned to the greenhouse. Preliminary tests gave a basis for estimating the temperatures at which the seedlings should be frozen to get differential killing. Seedlings of different ages were then frozen at various temperatures for different periods of time. In all cases notes were taken before freezing on the number of seedlings to a row, height, leaf stage, and vigor. After freezing, notes were taken on several dates, on freezing, injury, and vigor.

In each study the survival percentage was determined for each row in each replication. Means were obtained by averaging the results of all replications for each treatment. Standard errors of these means were calculated separately for each treatment. Standard errors of the differences were then calculated to determine the significance of these differences for the various comparisons that were made. In this study the 5% point was used as the level for significance and the 1% point as the level for high significance. It is known that there was probably some association between seedling survivals in the various comparisons, but it was

assumed that the correlation was zero. In many cases the number of variates making up the means was different and paired comparisons could not be made. If there had been a correlation of zero, then the value necessary for significance would have been the same in both the paired and unpaired relationships.

EXPERIMENTAL RESULTS

FIELD SURVIVAL

Geographical strains of the warm temperature species, *Bouteloua gracilis*, *B. curtipendula*, *Panicum virgatum*, and *Andropogon furcatus*, were studied for winter survival in the field at Mandan, N. Dak., from 1937 to 1941. After the winter survival of each strain was obtained, the data for strains of each species within geographical regions of the Great Plains were grouped together. Table 1 gives the data obtained for the four species within the Northern, Central, and Southern regions. Strains from North Dakota were included in the Northern region; those from Nebraska, Iowa, Wyoming, and northern Colorado in the Central region; and those from southern Kansas, Oklahoma, Texas, New Mexico, and Arizona in the Southern region.

TABLE 1.—*Winter survival of geographical strains of Bouteloua gracilis, B. curtipendula, Panicum virgatum, and Andropogon furcatus at Mandan, N. Dak., for the period 1937 to 1941, inclusive.**

Great Plains geographical region	No. of accessions	No. of plants fall of 1937	Percentage survival winter of				Percentage of surviving plants showing winter injury winter of				Degree of injury to surviving plants†
			1937–38	1938–39	1939–40	1940–41	1937–38	1938–39	1939–40	1940–41	
Bouteloua gracilis											
Northern	5	158	100.0	100.0	100.0	100.0	5.1	5.7	22.2	7.0	0.8
Central	5	186	99.5	99.5	99.5	99.5	34.1	22.7	81.6	77.8	2.6
Southern	7	207	50.7	47.8	46.9	41.1	62.9	55.6	97.9	96.5	4.0
Bouteloua curtipendula											
Northern	7	214	100.0	99.5	99.5	98.6	6.1	12.7	20.2	9.5	1.0
Central	4	121	100.0	98.3	98.3	97.5	9.1	11.8	64.7	59.3	2.8
Southern	7	180	72.8	67.2	67.2	64.4	70.9	53.7	91.7	93.9	3.7
Panicum virgatum											
Northern	5	181	100.0	100.0	100.0	100.0	1.7	9.4	0.6	0.0	0.0
Central	6	246	100.0	100.0	100.0	100.0	2.0	26.0	1.2	0.4	0.2
Southern	10	449	76.2	75.7	75.5	75.3	36.3	19.4	18.9	34.6	2.4
Andropogon furcatus											
Northern	1	26	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0
Central	3	79	100.0	98.7	98.7	97.5	21.5	3.8	17.9	31.2	1.3
Southern	2	72	59.7	59.7	59.7	56.9	62.8	41.9	65.1	73.2	2.5

*All plants established in the spring of 1937.
†An index to injury of those plants still alive with greater numerical value indicating more severe injury. 0 indicates no injury; 4 indicates very severe injury.

It is evident from the data presented that strains of the same geographical origin for the warm temperature species included in the study react similarly to the winter climate. The northern strains are highly winterhardy, but survival decreases as the origin becomes more southerly. *Panicum virgatum* is slightly more hardy than the other three species, but it is not advisable to use strains of even this species from the Central or Southern Plains in the Northern Plains because of their lack of adaptability.

Data obtained on the survival of individual strains showed a marked difference in the ability of different strains to survive the winter even though they originated within the same locality. This suggests the possibility of selecting strains with greater winterhardiness.

A gradual decline in vigor of plants of southern strains which have survived has been apparent. During the first year of growth, the southern strains of the warm temperature species were much more vigorous than northern strains. This was still true in the second season of growth even though winter injury had been considerable. Strong seed stalks and heads were produced the second season. It was evident in the third and fourth seasons that most plants of southern origin had been greatly weakened with an increase in both complete and partial killing. Fig. 1 shows differences in winterkilling and size of geographical strains of *B. gracilis* in 1941. Other warm temperature species show these same general characteristics. A direct relationship in time of maturity was shown between the region from which a southern strain of a warm temperature species was obtained and its period of maturity in the north, the time of maturity being latest for those strains that originated farthest south. There was no apparent difference in time of foliage emergence between geographical strains within any one species.

Large numbers of geographical strains of the cool temperature species studied were planted in the field in 1937. Strains of *Agropyron smithii* from North Dakota, Nebraska, Kansas, and Texas were carefully watched for signs of winter injury but in no case was any observed. Southern strains of this species were in general more coarse, less leafy, and taller than northern types but flowered approximately on the same date, the seed being mature about the last week in July. Foliage emergence in the spring has been approximately the same for all strains regardless of geographical origin. *Bromus inermis* from Kansas, Nebraska, and Canada has shown no signs of winter injury. Here again foliage emergence dates were approximately the same for all strains, as were the flowering dates. Seed was mature during the second week in July for the 4-year period included in the study. *Agropyron cristatum* strains were obtained from as far south as Nebraska, but no apparent difference was shown between these strains and those from North Dakota. No winter injury occurred and seed was mature on all strains during the second week in July. Differences in geographical strains of this species would be less likely to occur because the species has not been introduced into this country long enough for much natural selection to have occurred in the various regions where it is grown.

ARTIFICIAL FREEZING SURVIVAL

Seedlings of warm temperature species, 35 and 65 days old, respectively, were hardened as described and frozen at a temperature of −18° C for a 24-hour period. Six replications were used in studying each age group. Counts made 9 days later showed no survival of any seedlings, except those of the *Agropyron cristatum* check. It was evident that this temperature and exposure were much too severe to show differential killing. Seedlings of the 12 *A. cristatum* checks that were 63 days old averaged 61.46% survival and those 35 days old 50.00% survival. Evidence obtained in this first freezing trial showed the ability of *A. cristatum* seedlings to survive a much lower temperature and greater exposure than those of warm temperature species. Data presented later will show the similarity of the other cool temperature seedlings to *A. cristatum* in their ability to survive cold temperatures. This fact may partially explain why early fall field plantings of warm temperature species are generally unsuccessful while those of cool temperature species are generally successful.

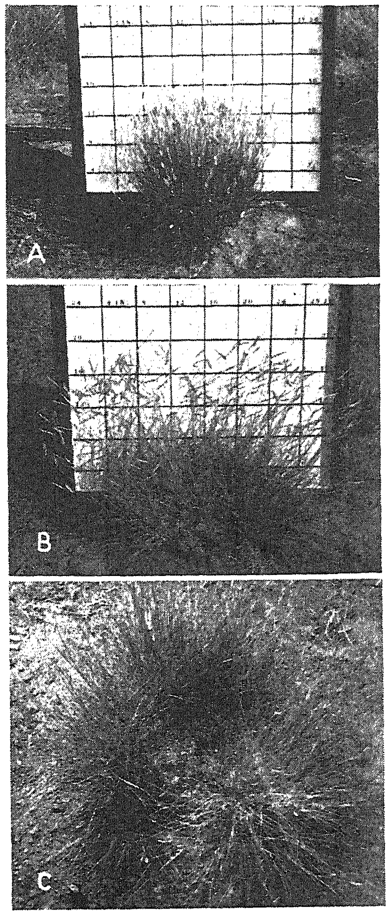

FIG. 1.—Typical plants of geographical strains of *Bouteloua gracilis* grown at Mandan, N. Dak., in 1941. All plants 5 years old. A, North Dakota strain with no evidence of winter injury; B, Nebraska strain with partial killing, also larger and later in maturity; C, Texas strain with greater winter injury and still later maturity.

Good differential killing was obtained when seedlings 69 days old were frozen at −10° C for 9 hours. This is shown in Table 2. *Bouteloua gracilis* and *B. curtipendula* reacted very similarly at this temperature and exposure. There was no significant difference in the survival of North Dakota and Nebraska strains, but both survived better than Texas strains. The Kansas strain of *Andropogon furcatus* gave a higher survival than that from North Dakota, but this was probably due to the greater vigor and more advanced growth of the Kansas strain. *Panicum virgatum* from North Dakota showed higher survival than that from Nebraska and Oklahoma. *B. gracilis* and *B. curtipendula* from North Dakota and Nebraska gave highly

TABLE 2.—*Seedling survival of warm temperature species frozen at two ages at one temperature and for two periods of time.*

Accession No.	Species	Origin	Percentage survival at –10° C		
			69-day seedlings frozen 9 hours*	41-day seedlings†	
				Frozen 9 hours	Frozen 6 hours
8	*B. gracilis*	Mandan, N. Dak.	85.56± 5.0	0.00	15.27± 9.9
51	*B. gracilis*	Sidney, Neb.	93.56± 4.3	0.00	13.70± 8.9
669	*B. gracilis*	Temple, Tex.	48.12±14.4	0.00	3.70± 3.7
952	*A. cristatum* (check)	Mandan, N. Dak.	96.66± 3.3	96.70± 3.4	92.60± 7.4
99	*B. curtipendula*	Mandan, N. Dak.	84.28± 8.0	7.40± 7.4	44.93± 4.4
163	*B. curtipendula*	O'Neill, Neb.	85.66± 4.3	0.00	19.43± 4.4
832	*B. curtipendula*	San Antonio, Tex.	19.18±16.0	4.17± 4.2	6.67± 6.6
10	*A. furcatus*	Mandan, N. Dak.	2.86± 2.8	10.73± 6.5	29.30±16.8
152	*A. furcatus*	Manhattan, Kans.	29.10±10.8	6.67± 3.4	10.37± 5.9
830	*A. furcatus*	San Antonio, Tex.	13.50± 7.1	0.00	17.03± 6.6
353	*P. virgatum*	Mandan, N. Dak.	16.22± 2.3	0.00	3.33± 3.3
52	*P. virgatum*	Sidney, Neb.	4.00± 2.6	0.00	6.67± 3.3
206	*P. virgatum*	Muskogee, Okla.	2.00± 2.0	0.00	0.00
952	*A. cristatum* (check)	Mandan, N. Dak.	100.00	100.00	96.67± 3.4

*Average of five randomized replications.
†Average of three randomized replications.

significant survival over *A. furcatus* and *P. virgatum* from North Dakota, Nebraska, or Kansas.

Another group of seedlings 41 days old was hardened, as usual, and frozen at −10° C for 9 hours. As is shown in Table 2, survival was much lower than that of the seedlings which were 69 days old. In many cases there was complete killing. It was impossible to calculate the standard error of the difference for most comparisons because of the low survival at this temperature and exposure. In those cases where some survival occurred no significant differences were apparent between geographical strains of the same species. When the 41-day seedlings were frozen for only 6 hours at −10° C, survival was much higher.

The *A. cristatum* checks showed continued high survival. Differences in seedling survival of the warm temperature species frozen for only 6 hours were not significant. It is interesting to note the low survival of *P. virgatum*. This is true in spite of the fact that seedlings of this species were more vigorous than those of any other species except *A. cristatum*.

In all cases seedlings of the various geographical strains showed striking differences in type and rate of growth. *B. gracilis* seedlings from North Dakota were much shorter than those from Nebraska and Texas, with tillers developing more rapidly. *A. furcatus* strains from Kansas and Texas were much more vigorous and rapid growing than the North Dakota strain. The Oklahoma *P. virgatum* grew much more rapidly and much taller, with fewer tillers than that from Nebraska and North Dakota.

Seedling survival of cool temperature species was much higher than that of warm temperature species when frozen artificially at the same age, temperature, and exposure. Seedlings of cool temperature species 35 and 63 days old were frozen at −18° C for 24 hours. Data presented in Table 3 show the results obtained with the 63-day seedlings. Survival obtained from the two age groups was similar in character. At this temperature cold injury was severe and mortality high. Variation in the ability of the various strains to survive was great and standard errors were high. It is evident, however, that *Agropyron cristatum* and *A. smithii* have greater cold resistance at this age than *Bromus inermis* as there was no survival of the latter species. The *A. cristatum* check showed no survival. This was due to the fact that the seedlings had become infected with root-rotting organisms before transplanting. Most of the seedlings died before freezing. The remaining few were so weakened that they could not withstand the low temperature. Other strains were not infected.

Since a temperature of −18° C for 24 hours was too severe to allow for survival of *B. inermis* and for much differentiation between *A. cristatum* and *A. smithii*, the temperature was raised and exposure shortened for the next freezing trial. Seedlings 72 and 44 days old were frozen at −10° C for 22 hours. Table 3 gives the survival results of this trial. Both age groups reacted similarly to this temperature and exposure. Here again the percentage survival of *B. inermis* was lower than that of the other two species. *A. smithii* from North Dakota gave a significantly higher survival than the Texas strain,

TABLE 3.—*Seedling survival of cool temperature species frozen at three ages, at two temperatures, and for three periods of time.*

Accession No.	Species	Strain	Origin	Percentage survival			
				Frozen at −18° C	Frozen at −10° C		
				63-day seedlings frozen 24 hours*	72-day seedlings frozen 22 hours†	44-day seedlings‡	
						Frozen 22 hours	Frozen 12 hours
952	*A. cristatum* (check)	Standard	Mandan, N. Dak.	0.00	83.32±12.9	97.80± 1.5	72.20± 7.0
13	*A. smithii*	Bulk	Mandan, N. Dak.	30.00±16.3	92.78± 4.9	89.26± 6.5	96.67± 3.4
449	*A. smithii*	Bulk	Manhattan, Kans.	11.67± 4.8	78.66±13.7	80.00± 5.9	96.67± 3.4
668	*A. smithii*	Bulk	Temple, Tex.	0.00	47.24±12.3	40.00±10.2	70.00± 8.3
750	*B. inermis*	Parkland	Canada	0.00	38.82± 9.1	38.89±14.5	60.00±15.6
1250	*B. inermis*	Commercial	N. Dak.	0.00	67.88± 6.9	46.67±14.8	53.33±14.8
1253	*B. inermis*	Commercial	Kansas	0.00	65.00±11.2	26.67±12.2	58.13±16.3
23	*A. cristatum*	Fairway	Mandan, N. Dak.	15.09± 9.3	100.00	96.67± 3.4	96.30± 3.8
96–24	*A. cristatum*	Standard	Mandan, N. Dak.	11.61± 5.4	93.46± 2.8	100.00	96.67± 3.4
1227	*A. cristatum*	Standard	Nebraska	12.70± 7.5	76.20±11.4	78.33±11.9	95.83± 4.2

*Average of six randomized replications.
†Average of five randomized replications.
‡Average of three randomized replications.

but the difference between the North Dakota and Kansas strains or the Kansas and Texas strains was not significant. When standard errors were calculated, including all strains as a group, within each species, it was found that *A. cristatum* survival was higher than that of *A. smithii* and *A. smithii* higher than that of *B. inermis*. When 44-day seedlings were frozen at −10° C for only 12 hours survival was higher than at longer exposures, but the same general relationship existed as to the survival of the various cool temperature species.

In considering the relation of height, vigor, and stage of development in relation to survival, it was found that *B. inermis* seedlings were taller, more vigorous, and further advanced in development than those of the other two species. Seedlings of the Parkland strain were slower growing, less vigorous, and shorter than North Dakota and Kansas *B. inermis*. *A. smithii* seedlings developed tillers more slowly than those of the other two species and there was little variation in strains. Fairway *A. cristatum* was finer leaved, shorter, and had a more rapid development of tillers than other strains of this species.

Two series of cool temperature species clones were frozen artificially. In one series they were hardened as usual and frozen at −21° C for 24 hours, thawed at 2° C for 48 hours, and again frozen at −10° C for 24 hours. The other series was frozen at −20° to −23° C for 24 hours. In both trials the temperature and exposure were too extreme and survival was low. A few new shoots started from at least one plant of each strain of *A. cristatum*, but none from any plants of the other two species. These new shoots soon died, however. The fact that *A. cristatum* plants started to make growth suggests that this species may be more resistant to extreme cold and exposure in the clonal stage than *A. smithii* and *B. inermis*. It is believed that greater survival would have been secured if a hardening period of more than 7 days at 2° C had been used.

Clones of the warm temperature species were also frozen at various temperatures and exposures. Since these species tend to become dormant in the fall regardless of temperature, the data obtained were not considered reliable. Experience in handling these species indicates that artificial freezing studies with warm temperature species could best be carried on in the spring after growth had started but before seed stalks are produced.

Observational notes were obtained on the speed at which the leaves of the various species were frozen after being placed in the freezing chamber. Almost without exception, leaves of both seedlings and clones of cool temperature species were frozen more rapidly than those of the warm temperature species. This may have been caused by a higher water content of the leaves of the cool temperature species. In many cases the leaves of the latter species, even though frozen stiff, would thaw out and not be injured. The warm temperature species froze more slowly, but if frozen, lacked the ability to revive after thawing. Freezing injury to young leaves was generally more severe than to more mature tissue. The first injury occurs at the tips of the leaves. More severe treatment often caused complete killing; or if new growth was produced, it came from the crown of the plant or from rhizomes.

DISCUSSION

A true inherited difference is apparent in northern and southern strains of warm temperature species of grasses as to their ability to survive cold temperatures. This fact is indicated in both the seedling and mature plant stage. The widely separated geographical strains of warm temperature species studied most certainly show a different physiological response throughout their life history to photoperiod and climate when grown at Mandan, N. Dak. Southern strains seem to have less ability to harden off either as seedlings or mature plants. Seedlings of warm temperature species from southern regions are more susceptible to freezing injury than seedlings of these species from northern regions, and much less capable of withstanding low temperatures than seedlings of cool temperature species.

In the mature plant stage southern strains of warm temperature species are so late in maturity that fall frosts catch them before maturity and before starting to become dormant while they are still in a more or less vigorous growing condition. Northern strains have at least started to become dormant before the first freeze. It appears that the warm temperature species must be relatively dormant when the first freeze comes to show high survival.

Both northern and southern strains of cool temperature species mature early in the summer and do not show the marked difference in growth type and vigor as related to origin. Even though these species are growing vigorously, as they often are in the fall, no cases of winterkilling have occurred. It is the inherent character of these species to be more hardy than the warm temperature species. The data on seedling survival are interesting in that the Texas strain of *A. smithii* did not survive artificial freezing as well as did more northern strains. Field results have not borne this out. In the case of *B. inermis* the Kansas strain did not differ from the North Dakota strain. There was also little difference in *A. cristatum* strains of different origin as to seedling survival.

In the case of the latter two species differences would be less likely to occur since they are introduced species. Natural selection has probably not had time to bring out the marked differences in various geographical strains as are found in the native species.

SUMMARY

The purpose of this study was to obtain information on the resistance to low temperature of seedlings and mature plants of geographical strains of grasses.

Agropyron cristatum, *A. smithii*, and *Bromus inermis* are classified as cool temperature species because they make their maximum vegetative growth in the cool period of the growing season. *Bouteloua gracilis*, *B. curtipendula*, *Andropogon furcatus*, and *Panicum virgatum* are classified as warm temperature species because they make their maximum vegetative growth during the warmest period of the growing season.

Strains of the warm temperature species from the same general geographic origin react similarly to the winter climate at Mandan,

N. Dak. The average field survival of these species decreases as their origin becomes more southerly. There has been no injury to the cool temperature species in the field regardless of origin.

There is a definite tendency for seedlings of warm temperature species of northern origin to survive in greater proportion after artificial freezing than those of more southern origin. With cool temperature species the only significant differences were obtained with *A. smithii*. Seedlings of this species from the south were less resistant to cold temperatures than those from the north.

Under all treatments the *A. cristatum* seedlings gave higher survival than those of *A. smithii* and seedlings of *A. smithii* gave higher survival than those of *B. inermis*.

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EFFECT OF FERTILIZATION OF A CROWLEY CLAY LOAM ON THE CHEMICAL COMPOSITION OF FORAGE AND CARPET GRASS, *AXONOPUS AFFINIS*[1]

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THE value of commercial fertilizers for pastures has been the subject of considerable research in recent years. The chemical composition is particularly of value in areas where, as in Texas and particularly along the Gulf Coast, quality rather than quantity of forage is often the limiting factor in animal production. Some workers (1, 2, 3, 10, 11, 12)[3] have studied the effect of fertilizers on the chemical composition of single species of pasture plants, but most of the work has been done on changes in botanical composition of the pastures and in chemical composition of the mixed herbage. This paper presents a study of variations in yield and protein, phosphoric acid, and lime in total forage and carpet grass, *Axonopus affinis*, caused by fertilization of a Crowley clay loam soil.

PLAN OF THE EXPERIMENT

Crowley clay loam is a soil type of considerable importance on the Gulf Coast Prairie of Texas. The particular area used was located at Substation No. 4 at Beaumont. Plots were 14 feet by 4 feet 7 inches. Forage consisted principally of carpet grass with small amounts of Dallis grass, *Paspalum dilatatum*, lespedeza, *Lespedeza striata*, white clover, *Trifolium repens*, and black medic, *Medicago lupulina*. Six different fertilizer treatments were made as follows: O, none; N, nitrate of soda, 80 pounds per acre; A, sulfate of ammonia, 100 pounds per acre; P, superphosphate, 20%, 160 pounds per acre; AP, combination of A and P; APK, combination of A and P, plus 32 pounds per acre of muriate of potash.

A second series of six plats received the same fertilizers plus lime (L) at the rate of 1 ton per acre. Fertilizers were applied about the middle of January of each year from 1935 through 1939. Lime was applied in 1935, 1937, and 1939. This series of treatments was replicated four times.

Samples of soil at two depths, 0 to 6 inches and 6 to 12 inches, were secured from the 48 plots. Samples from the four plots receiving the same treatment were composited and analyzed for total nitrogen, active (0.2 N nitric acid-soluble) phosphoric acid, and pH. Potash was not determined, but the soils were probably well supplied with that constituent (5).

Forage was mowed with a lawn mower each month of the growing season (March through September) and in December, 1938, and November, 1939. A part of the clippings was taken for fresh and air-dry weights. Samples of carpet grass were separated from the dry samples. The samples of carpet grass (or of the remaining forage) from the four plots receiving the same treatment were then combined, ground in a Wiley mill, and analyzed for protein, phosphoric acid, and

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[3]Figures in parenthesis refer to "Literature Cited", p. 565.

lime. From the weights and analyses of the carpet grass and of the residual forage, the analysis of the original total forage was calculated. Data for 180 yields and percentages of protein, phosphoric acid, and lime in 180 samples each of total forage and carpet grass were secured. This large volume of data is not presented in detail because of the limitations of space. Average yield and composition for the fertilizer treatments are given in Table 1; those based on dates of clipping are given in Table 2.

EXPERIMENTAL RESULTS

THE SOILS

Nitrogen in the surface soils averaged 0.131% on the unlimed plots and 0.121% on the limed plots, and in the subsoils, 0.108% and 0.098% respectively. The limed plots were slightly, but not significantly, lower in total nitrogen. The pH values of the same soils averaged 5.8, 6.6, 5.9, and 6.2, respectively. Some downward movement of the lime is apparent.

Active phosphoric acid was low in all of the soils. Averages for the four groups of plots were for (a) no phosphate and no lime, (b) phosphate and no lime, (c) no phosphate but limed, and (d) both phosphate and lime, 22, 23, 24, and 32 p.p.m. in the surface soil and 17, 18, 23, and 20 p.p.m. in the subsoil, respectively. At the time the soil samples were collected (January, 1938), the superphosphate added contained the equivalent of a total of 96 pounds of phosphoric acid per acre. Very little of this appears in an increase in active phosphoric acid in the soil. Phosphoric acid in the forage accounts for only a small part of the total added. Evidently, most of the phosphoric acid added was combined in compounds which were insoluble in 0.2 N nitric acid. Lime with the superphosphate considerably reduced the formation of these compounds, but the increase in active phosphoric acid in these plots accounts for only about 20% of the total added. The lack of significant increase in active phosphoric acid in the unlimed plots of this soil is in agreement with results reported for a similar soil (Lake Charles clay loam) at Angleton in which active phosphoric acid showed no significant increase except with very high applications of superphosphate (8).

EFFECT OF FERTILIZERS ON YIELDS OF FORAGE

Nitrate of soda significantly increased the yields of forage over the 2-year period. The increase in yield from the limed plots (22%) was slightly greater than that from the unlimed plots (16%) and considerably greater in 1939 (25%) than in 1938 (16%). Sulfate of ammonia did not produce a significant increase on the unlimed plots (5%) but did on the limed plots (17%). Muriate of potash did not significantly increase the yield from any group of plots.

Superphosphate more than doubled the yields on the unlimed plots (increases of 105% in 1938 and 106% in 1939) and greatly increased those from the limed plots (75% in 1938 and 54% in 1939). Superphosphate greatly increased the growth of lespedeza which formed an important part of the forage only on plats which had received superphosphate. This indicates that the growth of legumes may be

BLE 1.—Total yields and average chemical composition of forage and carpet grass receiving different fertilizer treatments.

Treatment	Total yield of dry matter, lbs. per acre		Protein, %				Phosphoric acid, %				Lime, %			
			Total forage		Carpet grass		Total forage		Carpet grass		Total forage		Carpet grass	
	1938	1939	1938	1939	1938	1939	1938	1939	1938	1939	1938	1939	1938	1939
O	2,495	1,629	8.20	8.25	6.77	7.19	0.26	0.27	0.23	0.24	0.91	0.81	0.74	0.69
N	2,864	1,922	8.07	8.13	6.88	7.31	0.26	0.25	0.24	0.25	0.77	0.73	0.71	0.64
A	2,708	1,943	8.10	8.47	6.99	7.25	0.27	0.29	0.24	0.25	0.80	0.76	0.69	0.64
P	5,394	3,746	10.56	10.31	7.59	7.84	0.41	0.40	0.34	0.36	1.06	0.95	0.69	0.71
AP	5,601	3,659	9.79	9.80	7.61	7.61	0.40	0.39	0.35	0.37	1.00	0.85	0.71	0.69
APK	5,510	4,272	9.94	10.44	7.88	8.15	0.41	0.42	0.37	0.38	1.09	0.99	0.77	0.74
L	3,630	2,500	8.87	8.78	7.43	7.49	0.29	0.27	0.25	0.27	1.00	1.03	0.84	0.86
NL	4,251	3,237	8.76	8.80	7.81	7.81	0.28	0.30	0.25	0.27	0.90	0.95	0.74	0.83
AL	3,812	2,463	8.56	8.56	7.60	7.68	0.27	0.30	0.25	0.27	1.00	0.97	0.81	0.81
PL	5,703	4,017	11.06	10.79	8.61	8.59	0.46	0.42	0.39	0.39	1.26	1.16	0.84	0.90
APL	7,011	4,296	10.44	9.85	8.67	8.37	0.46	0.41	0.40	0.39	1.24	1.09	0.94	0.91
APKL	7,380	4,464	10.44	10.76	8.40	8.36	0.41	0.38	0.37	0.34	1.29	1.15	0.94	0.93

TABLE 2.—*Total yields and average chemical composition of forage and carpet grass clipped at different dates.*

Month	Total yield of dry matter, lbs. per acre		Rain between cuttings, in.		Protein, %				Phosphoric acid, %				Lime, %			
					Total forage		Carpet grass		Total forage		Carpet grass		Total forage		Carpet grass	
	1938	1939	1938	1939	1938	1939	1938	1939	1938	1939	1938	1939	1938	1939	1938	1939
Mar	507	100	1.44	0.72	13.37	12.32	11.00	10.56	0.50	0.39	0.44	0.38	1.59	1.55	1.04	1.19
Apr	—	100	—	0.79	—	11.13	—	8.79	—	0.36	—	0.32	—	1.29	—	0.92
May	386	538	9.22	3.52	9.53	8.69	8.88	7.90	0.34	0.34	0.33	0.32	1.12	0.83	0.96	0.73
June	860	178	5.52	1.64	8.78	7.67	7.63	7.50	0.34	0.30	0.32	0.31	1.00	0.78	0.79	0.73
July	1,117	1,095	2.84	4.55	7.04	7.98	6.13	7.18	0.38	0.38	0.31	0.35	0.73	0.65	0.62	0.56
Aug	1,216	579	7.27	2.95	9.40	9.94	6.62	7.88	0.35	0.35	0.29	0.32	1.07	0.83	0.75	0.62
Sept	526	518	4.77	2.25	10.19	9.35	7.85	6.09	0.34	0.33	0.31	0.33	1.03	0.85	0.70	0.74
Nov	—	70	—	4.71	—	10.32	—	6.73	—	0.31	—	0.27	—	0.85	—	0.70
Dec	102	—	7.76	—	6.65	—	5.58	—	0.18	—	0.16	—	0.75	—	0.65	—

conditioned largely by the supply of available phosphoric acid in the soil.

Lime increased yields by averages of 31% in 1938 and 22% in 1939. It increased the relative effect of nitrate of soda and sulfate of ammonia and decreased that of superphosphate. The latter fact indicates that liming increased the availability of the phosphoric acid already present in the soil. This indication is supported by the fact that active phosphoric acid was slightly higher in the limed soils than in the unlimed soils.

EFFECT OF FERTILIZERS ON CHEMICAL COMPOSITION

Nitrate of soda had no significant effect on the protein or phosphoric acid in either forage or carpet grass and caused slight but insignificant decreases in lime. Sulfate of ammonia had no effect upon the chemical composition of either forage or carpet grass. Results with nitrogenous fertilizers are different from those secured in most of the experiments reviewed by Vandecaveye (13), who concluded that, "applications of nitrogenous fertilizers for pasture grass and hay can be expected to affect increased percentages of nitrogen in the herbage." The difference in results may be due in part to difference in the species studied (14).

Potash had no significant effect on the chemical composition of forage or carpet grass. This was to be expected since the soil probably already contained sufficient potash for excellent growth (5).

Superphosphate caused increases of 29% in protein, 54% in phosphoric acid, and 26% in lime in total forage from the unlimed plots, while from the limed plots the corresponding increases were 28%, 48%, and 20%. Corresponding increases in carpet grass were 10%, 50%, and 6% on the unlimed plots and 12%, 46%, and 11% on the limed plots. The increase in lime content of the forage due to the application of superphosphate was as great as the increase due to liming. The difference in lime content of forage from plots which had received superphosphate but no lime and from those which had received lime but no superphosphate was not significant. The increase in lime content of carpet grass was not as large as that in forage but was still slightly significant. The results secured for superphosphate are in general accord with those secured by other workers (1, 2, 3, 10, 12, 14).

Superphosphate greatly reduced the number of samples which contained less than 0.33% phosphoric acid and less than 6.00% protein and were therefore probably deficient in phosphoric acid and protein for animal production (7). Assuming that 0.32% P_2O_5 is the critical point, phosphoric acid was not deficient in 171 samples. Phosphoric acid was deficient in 189 samples of which 163 were from plots which had not received superphosphate. Nineteen of the 26 samples from phosphated plots which were deficient in phosphoric acid were collected in November and December when growth had practically stopped. The date at which samples from the phosphated plats became deficient in phosphoric acid depended to some extent upon the weather. In 1938, a deficiency of P_2O_5 in the forage did not occur until December; but in 1939, with much less favorable

rainfall, a deficiency was observed in samples of carpet grass collected in September and most of the samples collected in November were deficient. Protein was deficient in only 18 of the 360 samples, of which 14 were from plots which had not received superphosphate and 12 from unlimed plots.

Lime increased the protein content of total forage by 5% and of carpet grass by 9%, the phosphoric acid content of forage by 7%, and of carpet grass by 9%, and lime content of both forage and carpet grass by 22%.

VARIATIONS WITH DATES

Variations in yield and chemical composition were much greater at different periods of growth than with different fertilizer treatments, as may be seen by comparing the data in Tables 1 and 2. The greatest variation in connection with dates was in the yields for 1938 and 1939. This was probably due to a difference in rainfall in the two years. The total yield in 1938 was 48% higher than in 1939. Total rainfall during the growing season in 1938 (38.82 inches) was 82% higher than in 1939 (21.33 inches). The rainfall in 1938 was distributed much better, no month having a marked deficiency, while March, April, and June of 1939 were deficient as shown by very low yields as compared with the same months in 1938. However, the difference in rainfall did not cause significant differences in average percentages of protein, phosphoric acid, or lime in either forage or carpet grass. The only appreciable difference between the two years was in the earlier appearance of samples deficient in phosphoric acid in the fall of 1939 as compared with 1938. The difference in chemical composition caused by the difference in rainfall was not nearly as marked as in the results reported for alfalfa and little bluestem in Oklahoma (4) in which an increase in rainfall decreased lime and increased phosphoric acid.

Variations in chemical composition at different dates through the year were not as large as those in yield, but the data show definite trends. Protein showed a general downward trend until July, after which it increased until late in the fall. When considered on a bimonthly basis the changes were highly significant. Phosphoric acid was high in samples of forage and carpet grass collected in March, low in those collected in December, 1938, and fairly uniform throughout the rest of the year. Lime decreased from March through July, after which there was a slight upward trend.

Forage was higher than carpet grass in protein, phosphoric acid, and lime, but the ratios between the two varied considerably with different dates and fertilizer treatments. The increase in protein due to liming was considerably greater for carpet grass than for forage, while that due to superphosphate was considerably greater for forage than for carpet grass. The increases in protein and phosphoric acid due to superphosphate were much greater in total forage than in carpet grass in March as compared with July, and on unlimed as compared with limed plots. Because most of the samples represented young material grown during the preceding month, there was not very much difference in chemical composition of

samples taken at intervals during the season (Table 2). However, mature samples collected in January and December, 1938, were relatively low in phosphoric acid and protein and did not vary significantly with different fertilizer treatments. Thus, although marked differences in the chemical composition of young plants occurred with different treatments (Table 1), these variations decreased as the plants approached maturity and protein and phosphoric acid dropped to low levels. This agrees with results already reported (4, 5, 7) for other forage in Texas.

SUMMARY

Protein, phosphoric acid, and lime were determined in total forage and carpet grass clipped at monthly intervals through two growing seasons in 1938 and 1939 from plots of a Crowley clay loam at Beaumont, Texas, which had received six different fertilizer treatments with and without lime. Unfertilized carpet grass and forage were often deficient in phosphoric acid, less frequently in protein, and not at all in lime.

Sodium nitrate produced a significant increase in yield but did not affect the chemical composition of total forage or carpet grass. Ammonium sulfate alone increased the yield of forage to some extent but had little effect on chemical composition. Muriate of potash had no effect upon either the yield or chemical composition.

Superphosphate greatly increased the yield and the protein, phosphoric acid, and lime content of total forage and of carpet grass. It decreased the number of samples which were deficient in phosphoric acid for animal production.

Lime alone increased yield of forage 45 to 53%. It also increased the protein, phosphoric acid, and lime in the total forage and in carpet grass.

Variations in yield and chemical composition were much greater with different dates than with different fertilizer treatments. Protein and lime decreased from early spring until July and increased from then until late fall. Phosphoric acid was high in the early spring samples and then fairly constant throughout the remainder of the growing season. Rainfall in 1939 was sufficiently lower than that in 1938 to cause a large reduction in yield, but the difference in rainfall did not significantly affect the chemical composition of forage or carpet grass.

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EFFECT OF SURFACE STONES ON EROSION, EVAPORATION, SOIL TEMPERATURE, AND SOIL MOISTURE[1]

J. LAMB, JR., AND J. E. CHAPMAN[2]

SURFACE stones on cultivated lands are usually regarded as a nuisance, and are often removed at considerable expense. Examination of clean-cultivated sloping fields after heavy rains shows that the flat stones form miniature soil-saving dams and terraces. The stones break the fall of the rain drops, and it has been suggested that they also might act as a mulch and decrease surface evaporation. Areas under the larger stones frequently show worm and insect action, with the soil moist and granular, and, probably, absorptive.

Stones are common on farm lands and frequently present a serious agricultural problem. Thus, information in regard to their action on soil and water conservation is of value and should help in directing cultural practices.

There is little mention of this problem in soil literature. Buck (1)[3] states that the Chinese use several inches of gravel as a mulch for annual grain crops, removing the stones each year before seeding. Brailowsky[4] reports that flat stones have been used with success to conserve moisture and prevent weed growth in a vineyard at Montpellier, France.

Duley and associates (2, 3) and many others have found that crop residues and plant mulches reduce runoff and evaporation thus increasing the moisture content of the soil and crop growth.

Evaporation studies have been numerous. In 1888, Russell (6) and, in 1894, King (5) used the Piche evaporimeter to determine the evaporation from a free water surface and from soils. Wilson (8) used the Livingston atmometer in his 10-year study of evaporation conditions in Ohio. A modification of this principle, the humidity gradient, was used by Thornthwaite and Holzman (7). All these studies of atmospheric moisture conditions show evaporation to be an important cause of moisture loss from soil. However, where direct weighing methods have been used to measure evaporation, as reviewed by Harris and Robinson (4), there has been some conflict in opinions as to the importance of such loss of water from soil.

The studies that follow were made at the Arnot Soil Conservation Experiment Station operated by the U. S. Dept. of Agriculture and the Cornell University Experiment Station. The Station is located at the University Arnot forest 17 miles southwest of Ithaca, N. Y., at an elevation of 1,200 to 1,900 feet.

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[1]Contribution from the Division of Research, Soil Conservation Service, U. S. Dept. of Agriculture, in cooperation with the Cornell Agricultural Experiment Station. Received for publication January 15, 1943.

[2]Project Supervisor and Junior Soil Technologist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 578.

[4]Information supplied by A. Brailowsky, former Special Assistant in Research, New York State Agricultural Experiment Station, Geneva, N. Y., by letter December, 1941.

METHODS

There were three types of plots used, namely, large field plots, small field plots, and small weighed boxes. Erosion and soil temperatures were determined with 1/100-acre field plots, 6 feet wide and 72.6 feet long. Small field plots, 5 by 5 feet were used to study the effect of surface stones on soil moisture. Evaporation, percolation, and additional runoff data were obtained by direct weighing of soil boxes 36 inches long, 16 inches wide, and 9 inches deep, which held an 8-inch depth of soil.

Evaporation rates from a free water surface were measured by means of a class A evaporation pan, and a 10-inch pan supported by a recording rain gage gave continuous rates. Three to four standard rain gages were used to measure the rainfall. Soil temperatures were secured by means of copper-constantan thermocouples and a potentiometer calibrated in degrees Fahrenheit. Soil moisture conditions were determined by tensiometers.

The field plots, small plots, and all equipment were located within a radius of 150-feet, on an 18 to 20% southeast slope. The soil series was the Bath flaggy silt loam, with about 18% of the normal cultivated surface covered with flat sandstone fragments ranging from 1-inch to flagstone size.

The A series field runoff plots had been completed in April 1935. They were surrounded by steel border plates that projected 6 inches above the soil surface and penetrated to a depth of 12 inches below, and water and soil were collected in covered tanks at their base. These plots were spaded to plow depth once each season, late fall or early spring, and the stones mixed through the entire plow layer. All the fallow plots were cultivated at the same time the corn was cultivated. The shallow summer cultivation tended to work the stones to the surface, and two to three times a year stones above 2 inches in largest dimension were removed from plot A-7 and weighed. No stones were removed from plots A-5 or A-8. The B series field runoff plots were established from an old sod of mixed clover and grass July 1939. Plot B-15 was mulched with oat straw at the rate of 6-tons per acre. Plot B-16 was clean cultivated with no crop.

Five small field plots, 5×5 feet, were spaded to plow depth from an old sod of mixed clover and grass during August 1941. The plant stems and roots were removed from the plots at the time. The treatments were as follows: Stones removed above 2-inches largest dimension; natural stone cover on approximately 18% of surface; stones added to give approximately 65% stone cover; stones added to give 4-inch layer of stones, 100% stone cover; stones added to give 8-inch layer of stones, 100% stone cover.

Soil water tensions in these plots were secured at depths of 3, 10, and 20 inches. After September 15, the stones were removed and water sprinkled on the plots as needed until the tensions of the soil water of all the plots approached the same level. The stones were then replaced, but not on the same plots, as indicated later in Table 5.

The direct weighing soil boxes were placed in a shallow pit so that the surface of the soil in the boxes would be on the same plane as the adjoining field soil, and all apertures between and about the boxes were covered to reduce air movement. The boxes were weighed with steelyards to an accuracy of 0.2 pound, equivalent to 0.01 inch of water. A double bottom allowed free percolation. In the summer of 1938, eight soil boxes were each filled with well-mixed dry surface soil consisting of 186.2 pounds (oven-dry basis) of material which passed through a ¼-inch screen, and 63.5 pounds of stones that did not pass through the same screen. This

ratio of stones to fine material represented field conditions. In six boxes, the flag stones were mixed through the mass of the soil. In two boxes, stones with the long dimension of 2 inches or more, which amounted to 17 pounds per box, were placed on top of the soil to cover approximately 65% of the surface.

Few stones exceeded 6 inches in the long dimension. The boxes to receive treatments were selected at random. The character of the surface cover and the treatments are indicated in Fig. 1. Each spring the fallow soil was cultivated about 6 inches deep, with the surface stones on the soil of the 65% stone treatments removed before and replaced after the process. The soil of two of the 18% stone cover boxes was held in a freshly cultivated condition during the season of 1940. Weeds were removed as soon as they appeared in all treatments. Oat straw with which two other boxes were covered at the rate of 6 tons per acre was held in place by 1-inch mesh poultry netting. All boxes, covered in the winter but not insulated to any extent, were exposed to freezing temperatures. It was assumed that after correcting for rainfall, percolation, and runoff, the losses in weight of the soil boxes from day to day were due to loss of water by evaporation. No attempt was made to measure the amount of vapor condensation.

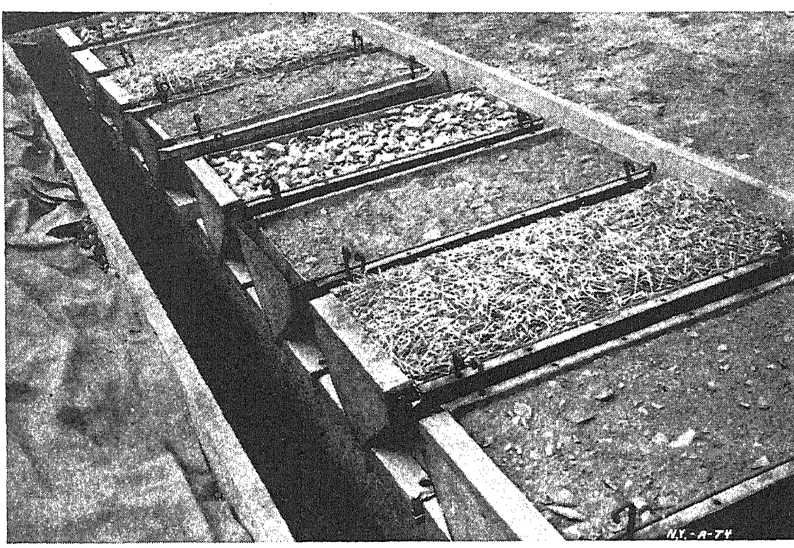

FIG. 1.—Soil weighing boxes partly stripped to show construction details. Cover treatments from left to right are 67% stone, 18% stone, oat straw, 18% stone, 67% stone, 18% stone, oat straw, and 18% stone.

EXPERIMENTAL RESULTS

EFFECT OF SURFACE STONES ON EROSION FROM FIELD PLOTS

The water and soil losses from the series A field plots A-5 and 8, stones in place, and plot A-7, stones removed, are indicated in Table 1. Plots A-7 and A-8 are shown in Fig. 2. Removal of the large stones almost doubled the water loss and in 1940 increased the soil loss more than six times. The soil loss has all been due to sheet erosion, and the loss of some of the finer portion of the soil seems to decrease

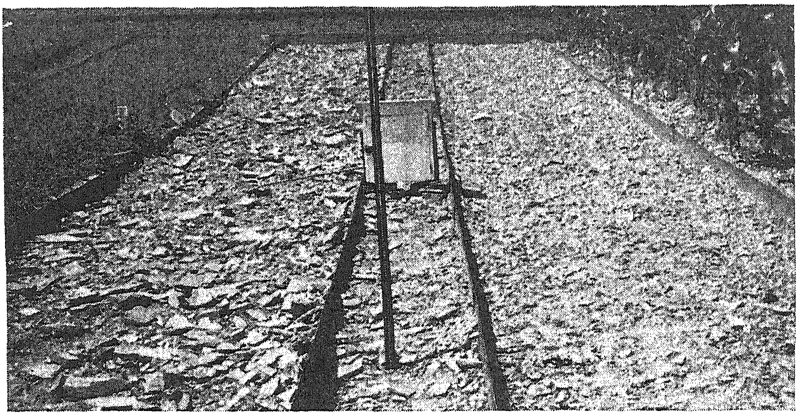

FIG. 2.—Arnot fallow plots A-7 surface stones about 2 inches removed, A-8 surface stones in place. The metal tubes in the soil are parts of tensiometers.

gradually the severity of the erosion. About 40% of this soil, while in place in the fields and where no stones have been removed will pass through a ¼-inch screen, but about 97% of the eroded material will pass through the same screen. Few of the stones that do not pass through are larger than ½ inch in long dimension.

TABLE 1.—*Effect of surface stones on soil and water loss from series A field plots.*

Year*	Rain-fall, inches	Stones in place, fallow, plot A-8		Stones removed, corn 1935–36–37; fallow 1938–39–40, plot A-7		Stones in place, corn, plot A-5	
		Water loss, %	Soil loss per acre, lbs.	Water loss, %	Soil loss per acre, lbs.	Water loss, %	Soil loss per acre, lbs.
1935........	22.7	15.0	17,127	13.8	16,150	8.2	8,520
1936........	20.4	13.2	30,179	8.7	17,495	4.8	8,546
1937........	31.3	20.1	26,973	18.8	18,886	10.2	6,522
Av. for 3 yrs.	24.8	16.1	24,760	13.8	17,510	7.7	7,863
1938........	20.9	18.1	14,646	23.6	22,491	9.0	4,446
1939........	16.8	15.4	8,212	25.0	24,746	15.0	9,782
1940........	23.0	8.2	5,496	19.6	32,730	5.0	3,433
Av. for 3 yrs.	20.2	13.9	9,451	22.7	26,656	9.7	5,887

*Period May through October.

EFFECT OF SURFACE STONES AND STRAW MULCH ON EVAPORATION FROM SOIL IN WEIGHED BOXES

The summer evaporation in central New York is appreciable, and a lack of soil moisture during the growing season frequently causes

reduced crop yields and crop failures. The introduction of commercial overhead irrigation systems, in some cases for crops like potatoes, is evidence of recognition of this condition.

The actual amount of water in each soil box on each weighing date in 1938 is presented in Fig. 3, expressed both as inches and as percentage of moisture in the soil. The percentage is based on the

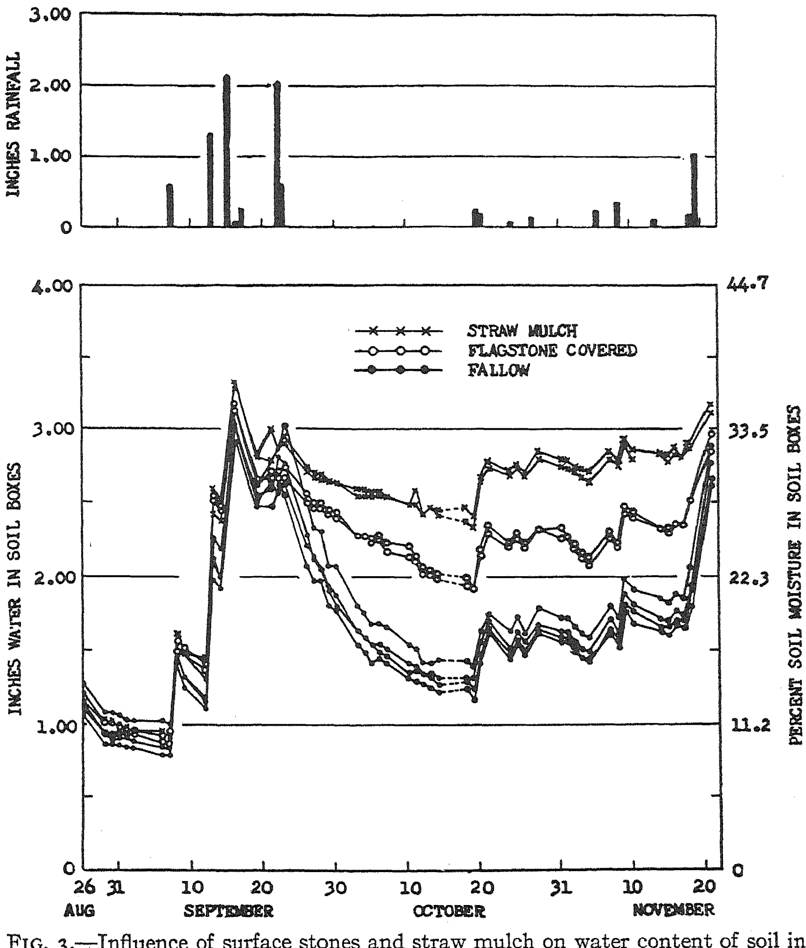

FIG. 3.—Influence of surface stones and straw mulch on water content of soil in individual weighing boxes, 1938.

dry weight of the material that passed through a ¼ inch screen. The initial moisture was about 12%. Before the first rain there was little evaporation and only slight differences in the amount lost from the variously treated soils. After there was sufficient rain to wet the soil, the treatments showed consistent differences and the weight losses from the replicates showed reasonably good agreement. At no time in 1938, after the soil was once wet, did the soil

under the straw mulch become as dry as the soil of either of the other treatments.

During a period of low rainfall, May 12 to July 20, 1939, not shown in Fig. 3, the straw-mulched soil reached practically the same moisture level as the soil under the 65% stone cover and 18% stone cover.

The data for 1940 are not unlike those of the previous years and are illustrated in Fig. 4. The frequent cultivation of the soil in boxes 3 and 7 caused the soil to hold more water for the period, decreased the runoff from 44 to 23% of the rainfall, but increased the evaporation from 50 to 77%.

During periods in 1939 and 1940 when the weights of soil boxes were obtained at frequent periods, the stones seemed to increase the

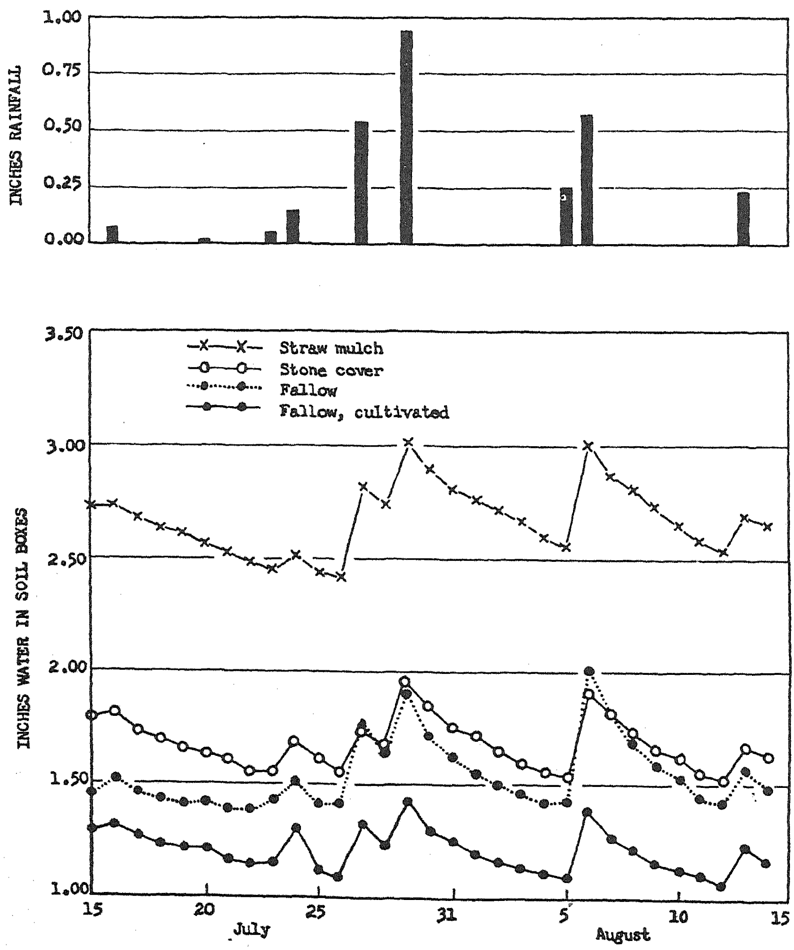

FIG. 4.—Influence of surface stones, straw mulch, and cultivation on water content of soil in weighing boxes, 1940.

percolation and decrease the evaporation slightly. The straw mulch decreased runoff and evaporation and increased percolation.

The maximum loss in weight by evaporation in any 24-hour period was 0.15 inch of water. As much as 0.77 inch of water has been lost between rainstorms. The rain of August 4, 1939, thoroughly wetted the soil of all the boxes, and during the next 4 days the total loss in weight attributed to evaporation from the clean-cultivated, no-crop soil was equivalent to 0.60-inch of water.

The average evaporation from the replicates and from a free water surface is shown graphically in Fig. 5. The rate of soil moisture loss was comparatively high from the soil of all boxes regardless of treatment the first few days, but less from the straw-mulched soil. During this period, the evaporation from the soil increased or decreased much the same as that from the free water surface. After 9 days, the evaporation rate from the soil was essentially the same from all treatments and on August 17 it was slightly higher in the case of the straw mulch and 65% flagstone cover. At this time there was more water present under the straw mulch and stone cover, the vapor pressure near the surface was probably higher than in the case of the drier soils, and this greater vapor pressure gradient with the atmosphere caused the higher evaporation.

It is probable that immediately following a rain the soil in the boxes had a higher moisture content and a higher evaporation rate than field soils. This could be true because of a perched water table resulting from a truncated soil section. In a dry period it may have had a lower water content than a field soil since there was no opportunity for upward movement of moisture from the sub-soil.

WATER-HOLDING CAPACITY OF SOIL UNDER STONES AND STRAW MULCH IN WEIGHED BOXES

The water content of the soil boxes following rains that caused considerable percolation should be near the maximum field capacity of the soil to hold water. During dry periods, small cracks appeared in the soil surface, but none seemed deep enough to influence percolation to an appreciable extent. The soils under the 65% stone cover and under straw have maintained more of the water-holding capacity of the original soil before packing than the soil with the lower percentage of stone cover (Table 2). The higher moisture content would indicate a physical condition that favored the retention of moisture.

TABLE 2.—*Percentage of water in soil of weighed boxes following rains that caused percolation.**

Date of rains	16–18% stones	65% stones	Straw mulch
Sept. 23, 1938	35.5	35.1	37.9
Sept. 30, 1939	22.1	27.3	30.0
Aug. 6, 1940	21.9	25.0	31.5
June 5, 1941	24.7	28.3	31.4

*Boxes weighed before appreciable evaporation occurred.

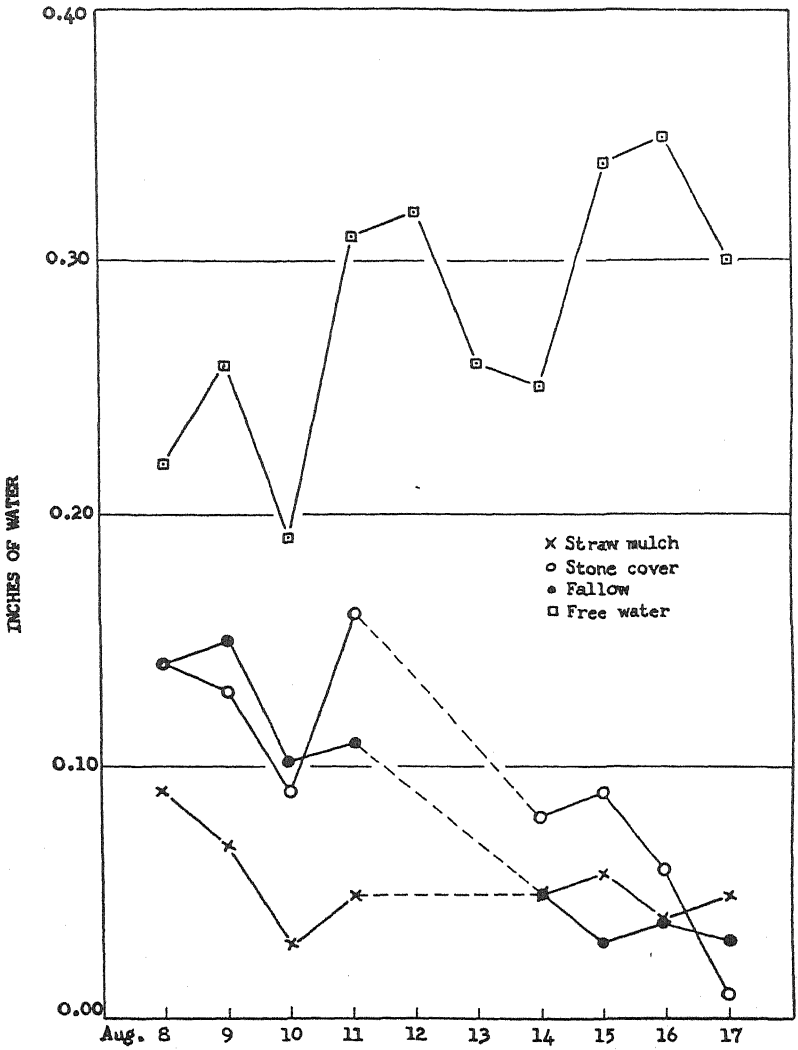

FIG. 5.—Evaporation from a free water surface and from the soil in weighing boxes after the rain of August 8, 1939.

COMPARISON OF RUNOFF AND SOIL LOSSES FROM SOIL BOXES WITH THOSE FROM FIELD PLOTS

The runoff from the soil boxes is higher on the average than that from field plots (series B) with comparable slope and treatment. The data in Table 3 are representative of the results from rains where runoff occurred. The soil loss was greater from the soil boxes than the field soils in the case of three rains and less for one rain.

TABLE 3.—*Runoff and soil losses from soil in weighed boxes and on series B field plots from four rains in 1939.*

Date of rains	Rainfall, inches	Soil boxes			Field plots	
		Stones 18% cover	Straw mulch	Stones 65% cover	B-16, stones 18% cover	B-15, straw mulch
		Runoff % of Rainfall				
Sept. 21, 1939..	0.45	70.7	2.0	41.3	16.6	0.9
Sept. 26, 1939..	1.39	51.7	1.2	42.2	17.1	0.7
Sept. 27, 1939..	0.96	63.8	1.4	42.7	8.1	0.6
Oct. 6, 1939....	0.37	68.6	2.2	54.6	46.6	0.5
		Soil Losses, Lbs. per Acre				
Sept. 21, 1939..	0.45	765	0	192	738	0
Sept. 26, 1939..	1.39	244	0	64	149	0
Sept. 27, 1939..	0.96	601	0	37	154	0
Oct. 6, 1939....	0.37	592	0	108	821	Trace

TABLE 4.—*Temperatures of field soils under fallow, 65% flagstone cover, and straw mulch.*

Hours of sun-light	Mean air tem-pera-ture, °F	Soil depth, in.	Temperature reading 9 a.m., °F			Temperature reading 2 p.m., °F		
			Fallow	Stones*	Straw†	Fallow	Stones	Straw
			Sept. 13, 1939					
7.6	50°	0	——	72.5°	56.5°	——	88.0°	69.0°
7.6	50°	1	62.5°	65.0°	57.5°	80.0°	83.0°	66.0°
7.6	50°	3	58.0°	60.0°	57.0°	74.0°	72.5°	64.0°
7.6	50°	10	57.5°	62.0°	57.5°	61.0°	61.0°	62.0°
7.6	50°	20	62.0°	66.0°	60.0°	61.5°	60.5°	63.5°
7.6	50°	30	64.0°	67.0°	60.0°	63.0°	63.0°	64.0°
			Sept. 15, 1939					
8.8	70°	0	——	88.0°	65.5°	——	109.0°	81.5°
8.8	70°	1	77.5°	81.0°	63.0°	99.0°	102.5°	74.5°
8.8	70°	3	69.5°	71.5°	62.0°	90.5°	89.0°	70.0°
8.8	70°	10	65.0°	67.5°	61.5°	69.0°	69.5°	64.0°
8.8	70°	20	63.0°	67.0°	61.0°	66.0°	65.0°	63.0°
8.8	70°	30	63.5°	65.5°	60.0°	64.5°	64.0°	63.5°
			Sept. 19, 1939					
5.8	55°	0	——	70.5°	58.0°	——	84.5°	68.0°
5.8	55°	1	63.5°	65.0°	57.0°	79.5°	79.5°	64.0°
5.8	55°	3	58.5°	60.5°	57.0°	74.0°	73.0°	63.0°
5.8	55°	10	62.5°	64.5°	60.0°	63.5°	63.0°	62.5°
5.8	55°	20	67.0°	68.0°	61.5°	64.0°	64.0°	64.0°
5.8	55°	30	66.0°	68.0°	61.5°	65.0°	64.5°	64.0°

*Reading secured under one of the larger stones at the center of an area some 4 feet in diameter where 65% of the surface soil was covered by a single layer of flat stones with sizes ranging from 2 to 10 inches the long dimension.

†Straw mulch 6 tons of oat straw per acre applied August 1939.

TEMPERATURE OF FIELD SOILS UNDER SURFACE STONES AND STRAW MULCH ON SMALL FIELD PLOTS

The soil temperatures were usually higher at the 1-inch depth under the stones (Table 4) than under the fallow at the same depth. The fallow temperatures were 14° to 24.5°F higher at the 1-inch depth than under the straw. It appears that the low temperatures under the straw caused less evaporation. The higher temperatures under the stones would counteract to a certain extent the tendency of the stones to reduce evaporation through obstructing diffusion of the vapor into the atmosphere.

EFFECT OF SURFACE STONES ON SOIL MOISTURE OF FIELD SOILS ON SMALL FIELD PLOTS

The tension of the soil water under the 4-inch layer of stones was consistently lower than under 65% stone cover, and the latter was lower than that under normal stone cover (Table 5). Shifting the stone cover treatment to different locations did not change the trends. Apparently, the differences in soil moisture behavior were due to the treatments and not to soil variation. With lower air temperatures and less sunshine in the second period, there was a tendency for the 65% stone cover to increase in effectiveness as a mulch.

TABLE 5.—*The average tensions of soil water under various stone covers for two periods of time in 1941.*

	Stone cover				
	Stone removed	18%	65%	100%, 4 in.	100%, 8 in.
	Aug. 16 to Sept. 15*				
Plot No.	5	3	4	2	1
Tension 3 in. depth†	35	36	21	6	10
Tension 10 in. depth	26	24	21	5	13
Tension 20 in. depth	36	38	39	18	37
	Sept. 24 to Oct. 14‡				
Plot No.	4	2	1	5	3
Tension 3 in. depth	39	47	17	12	10
Tension 10 in. depth	28	36	14	11	10
Tension 20 in. depth	33	28	23	26	20

*Rainfall, August 16 to September 15, 1.87 inches.
†Tensions are in cm of mercury at indicated soil depths.
‡Rainfall September 24 to October 14, 1.22 inches. Covers were removed and reestablished on plots as shown under plot number.

There seems to be little difference between the stone removed and natural stone cover treatments, and the same was true for the 4 inches and 8 inches of stone cover. The treatments were not continued long enough to influence to any appreciable extent the moisture content of the soil at the 20-inch depth. The difference in moisture condition of the surface soil was probably related to difference in loss by evaporation since the rains were gentle and little runoff

occurred during the studies. Water applied during the interval between periods was applied no faster than could be absorbed without runoff.

DISCUSSION

Since surface stones increase water absorption, decrease soil washing, and apparently reduce evaporation, there seems to be little reason for removing them from fields unless they definitely interfere with cultivation.

In New York the best sites for growing grapes and other fruits are the sloping lands adjacent to large bodies of water. Clean cultivation, especially where rows are off the contour, results in severe erosion. Many of these soils are stony and it may be advisable to use cultivating tools that work stones to the surface, such as the spring tooth harrow. Once a stone mulch is established, weeds might be controlled by toxic sprays, which later act as a nitrogen fertilizer to the grape vines or trees.

The high temperatures under stones may be one factor in the production of high-quality grapes on stony steep slopes. It may also help explain yields of over 50 bushels of corn per acre at the high altitude of the Arnot Station.

The low temperatures under a straw mulch could also help account for the success of such cool season crops as potatoes grown under a straw cover in the high summer temperatures of southwestern Illinois.

SUMMARY AND CONCLUSIONS

This study to determine the effect of surface stones on soil erosion and soil moisture was carried out to save many farmers the labor of unnecessary stone removal. Soil and water runoff from field plots was collected and weighed, and soil moisture and soil temperature conditions were noted. Soil in special boxes was weighed to determine the water loss by evaporation from the surface.

The removal of surface stones above 2 inches largest dimension on field plots approximately doubled the water runoff and increased soil loss as much as six fold.

A 65% stone cover compared to the normal 18% stone cover over the soil in weighed boxes slightly reduced the loss of soil water by evaporation, increased water absorption, decreased soil loss, and maintained a relatively high water-holding capacity.

A 6-ton per acre straw mulch cover over the soil in weighed boxes reduced the loss of water by evaporation, greatly increased water absorption, prevented soil loss, and maintained a high water-holding capacity.

A 65% stone cover on field plots increased soil temperatures and maintained a higher content of soil moisture than the 18% stone cover. A 4-inch layer of stones maintained a higher content of soil moisture than the 65% stone cover.

A straw mulch of 6 tons per acre gave soil temperatures at 1-inch depth as much as 24°F lower than at similar depths under the 18% stone cover.

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WHEAT VARIETAL REACTION TO DWARF BUNT IN THE WESTERN WHEAT REGION OF THE UNITED STATES[1]

C. S. Holton and C. A. Suneson[2]

THE growing of resistant varieties offers the only known method of controlling dwarf bunt, a disease now widely prevalent in sections of Montana, Idaho, Utah, and Washington. Fortunately, many of the varieties used in breeding for resistance to the ordinary bunt (2)[3] are also resistant to dwarf bunt.

Pathological researches and general observations have demonstrated several characteristics peculiar to dwarf bunt which are pertinent to practical control of the disease. Dwarf bunt attacks fall-sown wheat only and thus can be controlled by growing spring wheat. It appears to be largely soil-borne (1), thus precluding effective control by seed treatment. It cannot be reproduced effectively by seed inoculation with chlamydospores (4), thus increasing the difficulty of experimentation.

Isolated new outbreaks and local spread of dwarf bunt with instances of damage exceeding 75% have been observed during surveys in recent years. The disease has persisted in certain fields in Utah for more than 10 years under alternate cropping and fallow, despite intervening culture of varieties equal to Ridit in resistance. In the 1942 uniform dwarf bunt nursery at Clarkston, Utah, in a field thrice previously cropped to a resistant variety, infections ranged up to 90% in susceptible varieties. On the other hand, in northern Idaho, infestation in susceptible varieties such as Golden has declined appreciably since 1938, coincident with increased rainfall, introduction of crops other than wheat, and elimination of fallow. It is evident that adequate information on the causal organism and on the influence of environmental and ecological factors on the development of dwarf bunt in epidemic proportions is lacking. However, additional information on varietal resistance presented here should be helpful. The reaction of certain hard red winter wheats to dwarf bunt has been reported by Rodenhiser and Quisenberry (3).

MATERIAL AND METHODS

Fifty-two winter wheats, including commercial varieties, hybrid selections of potential value as commercial varieties or parent stocks, and varieties used in physiologic race identification were grown for 2 to 6 years in uniform nurseries at five locations. Nurseries were grown for 6, 5, 4, and 2 years, respectively, at Logan, Utah; Bozeman, Mont.; High Prairie, Wash.; and Malad and Troy, Idaho. High

[1]Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture, and the agricultural experiment stations of Washington, Idaho, Utah, and Montana. Received for publication February 11, 1943.

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[3]Figures in parenthesis refer to "Literature Cited", p. 583.

TABLE 1.—*The reaction of 52 varieties and hybrid selections of winter wheat to dwarf bunt in uniform nurseries grown at five locations in the western wheat region of the United States.*

Variety	C.I. No.	Nursery location, year tested, and percentage dwarf bunt											Weighted average
		High Prairie, Wash.			Bozeman, Mont.			Logan, Utah		Malad, Idaho		Troy, Idaho	
		1937	1938	1940	1938	1940	1942	1937	1942	1938	1940	1940	
Jenkin × Ridit	10081	0	—	—	—	—	—	0	—	—	—	—	0.0
Hussar	4843	0	0	0	1	0	1	1	1	0	0	0	0.5
Relief × Ridit	11908	—	—	0	—	0	2	—	0*	—	0	1	0.5
Relief × Ridit	11909	—	—	0	—	1	—	—	—	—	1	1	0.8
Martin	4463	0	3	0	1	0	2	0	2	0	1	0	0.8
Relief	10082	0	0	0	1	0	4	0	1*	0	3	0	1.0
Ashkof	6680	0	—	—	—	—	—	2	—	—	—	—	1.0
Ridit × Relief	11925	—	—	—	—	—	1	—	1*	—	—	—	1.0
Relief × Ridit	11905	—	0	1	1	0	—	—	—	5	0	1	1.1
Oro × Turkey-Florence	11864	0	0	—	3	—	—	3	—	0	—	—	1.2
Relief × Ridit	11904	—	0	2	2	0	—	—	—	4	1	0	1.3
Hard Federation × Martin	11692	0	—	—	—	—	—	3	—	—	—	—	1.5
Beloglina × Hussar	11513	1	1	6	1	1	—	3	—	0	0	1	1.5
Hussar × Hohenheimer	10068–1	0	0	0	11	1	7	2	1	0	1	0	2.0
Turkey selection	11530	0	0	0	5	0	7	4	3	0	0	3	2.0
Rex	10065	0	0	0	9	5	—	7	—	0	0	0	2.3
Hymar	11605	0	0	0	10	0	8	1	6*	5	0	1	2.8
Requa	11554	—	—	—	—	—	4	—	2*	—	—	—	3.0
Oro × Turkey-Florence	11865	0	0	1	8	1	—	22	—	0	1	0	3.6
Minturki	6155	0	2	5	5	7	3	0	18	1	2	1	4.0
Oro × Federation	11914	—	—	12	—	3	—	—	—	—	1	0	4.0
White Odessa	4655	0	—	—	—	—	6	6	4	—	—	—	4.0
Oro × Federation	11913	—	—	8	—	2	—	—	—	—	0	13	5.8

Ridit × Hohenheimer	11760	1	0	0	24	2	—	30	—	1	0	0	6.4
Albit	8275	0	0	—	28	—	5	5	7	1	—	—	6.6
Ridit	6703	0	1	16	9	8	18	11	5*	0	0	7	6.8
Rex selection	11689	0	0	1	28	0	13	15	7*	0	2	12	7.0
Ridit × Utah Kanred	11598	0	—	—	—	—	—	15	—	—	—	—	7.5
Ridit × Utah Kanred	11686	1	—	—	—	—	—	15	—	—	—	—	8.0
Ridit × Utah Kanred	11599	0	—	—	—	—	14	13	7*	—	—	—	8.5
Ridit × Utah Kanred	11597	0	—	—	—	—	—	18	—	—	—	—	9.0
Ridit × 15a	11924	—	—	—	—	—	20	—	2*	—	—	—	11.0
Brevon	11912	—	—	1	—	0	14	—	63*	—	0	5	13.8
Hohenheimer × Gold Coin	11698	1	—	—	—	—	—	32	—	—	—	—	16.5
Hohenheimer	11458	0	0	10	38	1	7	83	55	1	4	0	18.0
Oro	8220	4	11	30	49	19	58	37	20	1	0	18	22.5
Oro × Hybrid 128	11757	5	22	—	34	—	—	58	—	15	—	—	26.8
Oro × Hybrid 128	11758	3	12	—	43	—	—	55	—	23	—	—	27.2
Turkey selection	10016	9	—	—	—	—	—	56	—	—	—	—	32.5
Oro × Hybrid 128	11756	13	22	—	38	—	—	66	—	25	—	—	32.8
Turkey selection	11424–14	—	—	83	—	7	—	—	—	—	14	30	33.5
Kharkof	1442	15	11	53	43	41	—	88*	—	7	38	10	33.9
Turkey × Hohenheimer	11759	4	25	—	52	—	—	69	—	25	—	—	35.0
Turkey	6175	19	30	83	47	13	—	76	—	25	27	21	37.8
Rio	10061	11	55	60	20	16	68	74	75*	30	20	34	42.0
Carlson's Fife	11922	—	—	—	—	—	40	—	50*	—	—	—	45.0
Turkey selection	11424–8	—	—	80	—	7	—	—	—	—	53	55	48.7
Hybrid 128	4512	19	58	50	64	20	78	91	90	35	25	35	51.4
Turkey selection	11376	35	—	—	—	—	—	74	—	—	—	—	54.5
Yogo	8033	—	—	—	—	—	53	—	65	—	—	—	59.0
No Name	12301	—	—	—	—	—	58	—	83	—	—	—	70.5
Elgin	11755	—	—	—	—	—	63	—	90*	—	—	—	76.5

*Approximately the same percentage of dwarf bunt occurred on these varieties grown in the Winter Wheat Yield Nursery at Logan, Utah, in 1942, except for Brevon and Carlson's Fife, which had only 7 and 15% dwarf bunt, respectively.

infection percentages did not always occur. Consequently, usable data were obtained for only 2 years each at Logan and Malad, 3 years at Bozeman and High Prairie, and 1 year at Troy. Certain varieties were tested only 1 year and then discarded for various reasons.

Each variety was grown in duplicate rows at each station, the length of the rows averaging approximately 8 feet. The seed of all varieties was rendered smut-free by the treating process already described (2), and the treated seed was sown in soil that was presumed to be naturally contaminated with dwarf bunt spores. In some instances dwarf bunt spores were added to the soil at planting time, but there is no consistent evidence that better infection was obtained because of this artificial inoculation.

The percentages of dwarf bunt were determined on the basis of estimated total and smutted heads in a row. Usually actual counts were made on several rows in each nursery for the purpose of checking the accuracy of the estimates, which were always found to be accurate enough for the purpose of the experiments.

The data from Malad, Idaho, were obtained from the uniform bunt nurseries, described in a previous report (2), in which high infection with ordinary bunt also occurred. The determination of the reaction to both bunts was possible because of their distinct characteristics, though as is shown later, dwarf bunt was sometimes suppressed.

EXPERIMENTAL RESULTS

The data obtained are presented in Table 1 which gives the percentage infection at each station each year and the average for all stations weighted according to the number of years tested. Because all varieties were not grown at all stations in all years and because the infection level for stations and years was not always the same, a comparison based on the average is not strictly accurate. It is believed to be sufficiently so, however, for the purposes of this paper. The varieties are ranked according to the weighted average for all stations and years.

These averages show that 31 of the 52 varieties and selections tested had less than 10% dwarf bunt. Infection in the others ranged from 11% in C.I.[4] 11924 to 76.5% in Elgin. Among the resistent varieties are the commercial wheats Relief, Rex, Requa, Hymar, Minturki, Albit, and Ridit, while the susceptible group includes Oro, Kharkof, Turkey (C.I. 6175), Rio, Carlson's Fife, Hybrid 128, Yogo, No Name, and Elgin. Most of the hybrid selections tested are in the highly resistant group. The commercial varieties Relief, Ridit, and Oro comprise one or both parents in all but three of these selections. Only one variety, Jenkin × Ridit (C.I. 10081), showed no infection, but it was grown only 1 year at two stations and probably would have shown some infection in more extensive tests.

Among the different stations the heaviest infections were obtained at Logan, Utah, and the lowest at Troy, Idaho. These differences in infection may be due to differences in the physiologic races of the dwarf bunt organism present or in environmental factors influencing infection.

The results obtained with Oro are somewhat conflicting. This variety showed little dwarf bunt at Malad, Idaho, in contrast to

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

appreciable percentages of infection at the other stations. Oro has been one of the major commercial varieties in the Malad Valley where it frequently has had severe infestations of dwarf bunt. Consequently, the low percentage of infection on Oro at Malad was not due to resistance. The explanation may be that the Malad data were obtained from a bunt-inoculated nursery that carried high percentages of ordinary bunt which attacked Oro. In 1 year Oro showed 73% infection from ordinary bunt. From these results it appears that the ordinary bunt may be more aggressive and thus suppresses the development of dwarf bunt in this variety. Whatever the explanation, the behavior of Oro in the Malad nursery does not reflect its true reaction to dwarf bunt. Furthermore, three Oro × Hybrid 128 selections were fairly susceptible at Malad, as well as at Logan and Bozeman. Also, the infection of Brevon at Logan (63%) probably is not representative, owing to poor stands. Therefore, it would seem unwise to regard any variety as highly resistant to dwarf bunt unless that type of reaction is obtained at all stations where tests are made.

SUMMARY

The reaction of 52 varieties and hybrid selections of winter wheat to dwarf bunt in the western region was determined by nursery tests in five localities in Washington, Idaho, Utah, and Montana. Smutfree seed was sown in soil presumed to be contaminated with dwarf bunt spores. Infection apparently cannot be accomplished by seed inoculation. Thirty-one of the varieties, including Relief, Rex, Requa, Hymar, Minturki, Albit, and Ridit, had less than 10% dwarf bunt. This indicates that there is ample highly resistant stock for breeding purposes.

The highest infections were obtained at Logan, Utah, and the lowest at Troy, Idaho.

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IMPROVING AN ANNUAL BROME GRASS, *BROMUS MOLLIS* L., FOR RANGE PURPOSES[1]

P. F. KNOWLES[2]

BY FAR the major proportion of grasses on the Californian ranges are annual species, and most of them are introductions from Europe. These annuals have proved themselves to be extremely well adapted to the environmental conditions in the state, having superseded, under past and present range management practices, the original bunchgrasses that were abundant before settlement by Europeans. After germination of the seeds with the fall rains, and a long seedling period with the cool winter temperatures, the adaptability of these annuals is reflected by an abundant vegetative growth with the warmer temperatures of spring. The disadvantage of these annuals, however, is their seasonal character. They dry up quickly when the spring rains cease, the seeds shatter, and during the long dry summer period they are of little value for forage.

The University of California has underway a program to improve the quantity and quality of the forage grasses on the range. Major emphasis at the present time is placed upon the re-establishment of perennial grasses, particularly of the bunchgrass type. At the same time, however, some consideration has been given to the improvement of annuals, since in all probability they will always remain an important constituent of the range. One typical winter annual species, *Bromus mollis* L., commonly known as soft chess or soft cheat, was chosen for preliminary studies of the breeding possibilities of an annual. Very little is known about the introduction of this species into California. All reports (14)[3] indicate that this species was not present before 1870 but was very abundant in most regions by 1900.

The object of this study was to determine the extent of variation within this species, and, if possible, the relation of this variation to environment.

LITERATURE

No reports could be found of studies of the variation of natural populations of annual grasses. Turesson (18, 19), in Sweden, and Clausen, Keck, and Hiesey (7), in California, made detailed studies of the variation of natural populations of perennial species with different ecological conditions. The heritably different morphological and physiological plant types associated with the different ecological habitats were termed "ecotypes". Among annual dicotyledons Turesson (18) showed the presence of ecotypes in species of *Atriplex*. Clausen, Keck, and Hiesey (5, 6) have given preliminary reports on their studies of the annual *Madiinae*. The species of this group showed well-defined ecotypes in California.

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[2]Graduate student. The writer is indebted to Dr. R. M. Love, Assistant Professor of Agronomy, University of California, who gave generously of his time to advise on the direction of this study.

[3]Figures in parenthesis refer to "Literature Cited", p. 593.

Years of close grazing has tended to fix a prostrate growth habit in pasture plants. This was shown by studies of Gregor and Sansome (8) with *Lolium perenne* L., *Dactylis glomerata* L., and *Phleum pratense* L., and by more comprehensive studies of the same authors (9) on two forms of *Phleum pratense*. Stapledon (16) demonstrated the same condition in pastures of *Dactylis glomerata*. Anderson and Aldous (1) within collections of little blue stem (*Andropogon scoparius* Michx.) showed that the greatest variation existed between samples collected from regions that were great distances apart and subject to very different environmental conditions. Beddows (4) compared the yields of a number of strains of *B. mollis* but did not relate the variation to the sources of the strains.

MATERIALS AND METHODS

During the summers of 1940 and 1941 a number of collections of soft chess was made. The location and extent of these collections are given in Table 1.

The "strains" of Table 1 are each the progeny of a single panicle selection. The seed of each panicle selection was sown in a 15-foot row in early November, enough seed being sown to establish one plant in each 9 inches of row, or a total of 21 plants to a row. Five rows were sown to a bulk collection from Santa Cruz County. Rows were 12 inches apart. Every sixth row was sown to the same strain of soft chess which traced back two generations to a single plant. The end plants of each row were not used in studies of the strains.

Until the first of March there was little growth of the seedling plants. The warmer temperatures after this date encouraged vigorous development, but until March 15 there were no marked differences between strains. By April 1, however, there was considerable variation apparent, especially with respect to date of heading. Considerable data were collected from these strains, and the manner of their collection is indicated below.

Days to head.—The average number of days from seeding (November 8) to the date at which heading occurred was calculated for each strain. A plant was called headed when the first panicle began to emerge, and the nursery was checked every 6 days in this respect.

Plant habit.—Five habit classes, *viz.*, erect (e)[4], sub-erect (se), spreading (sp), sub-spreading (ssp), and decumbent (d) were established. This note was taken shortly after all plants of a strain had headed, and the note was taken on the complete row and not on the individual plants.

Plant height.—The height in cm of the tallest tiller of every plant in the nursery was taken, and the mean of each strain calculated.

Tiller number.—The number of tillers on all plants was determined just before maturity.

Plant weight.—The total dry weight in grams of all plants of a strain was determined, and the plant weight recorded as the mean weight of a single plant.

In late April a large number of the leaves of all plants were affected by a species of *Septoria* with the result that many of the leaves dried up. Smut, *Ustilago bullata* Berk,[5] was found in many of the strains, but in no case was it very severe. Leaf rust (species not determined) started late in the development of the plants and was recorded as a trace in most strains.

[4]Letters in parenthesis indicate the abbreviations for habit classes that are used in the tables.

[5]Species identified by G. W. Fischer, Associate Pathologist (Coop. U. S. D. A.), Washington Agricultural Experiment Station, Pullman, Wash.

Because the check rows showed a consistent variation in certain sections of the nursery, the characters height, tiller number, and weight of each strain were increased or decreased according to the performance of the check. This was done so that strains from different sections of the nursery could be compared.

Pollen mother cells (p.m.c.) for cytological study were obtained from 64 strains of soft chess. An attempt was made to sample the extremes of variation found in the nursery. Studies were carried out using temporary aceto-carmine smears made according to Love's technic (11). A number of photomicrographs were taken, all magnifications being $\times$ 820. Emphasis in cytological studies was placed on the chromosome pairing at first metaphase of meiotic divisions. The number of open and closed bivalents was recorded, as was the number of univalents. From most plants a total of 25 good p.m.c. was used. When first anaphase and tetrad material was available, any departures from the normal behavior were recorded.

EXPERIMENTAL RESULTS

REGIONAL VARIATION

Sampson (15) has classified the California ranges according to the life zone where they are found. The zones can be described briefly as follows: The Lower Sonoran includes the Great Valley of California and the Colorado and Mojave deserts; the Upper Sonoran comprises the lower foothill belt of grassland bordering the Great Valley and a slightly elevated chaparral belt between 1,000 and 5,000 feet; the Transition includes elevations between 2,000 and 7,000 feet and is characterized by the forest belt and includes the northern and central coastal areas; and the Boreal occupies the areas from 7,000 feet to the tops of the highest mountains. Bailey's (2) zone map of Oregon was used for that state. Strains of soft chess have been obtained from each of the first three zones, and the data on each of these strains are grouped accordingly in Table 1. Subgroupings are by counties.

The most conspicuous difference between the collections of soft chess from the different life zones was in the time required for heading to take place. The collections from the Transition Zone were distinctly later, and the degree of overlapping of extreme ranges for this character between the Transition and the Upper Sonoran was very small. The strains from the Lower Sonoran averaged earlier than those from the Upper Sonoran, but the degree of overlapping was considerable. Fig. 1 gives some idea of the range in maturity of this species.

Among the other plant characters there were none that exhibited distinct and consistent differences between life zones. Height, on the average, decreased from the Transition to the Lower Sonoran, but there was considerable variation within the zones. Collections from Tuolumne County were conspicuous in the nursery because of their greater height.

LOCAL VARIATION

One of the purposes in collecting and growing these samples of soft chess was to discover superior strains that might improve this species for range purposes. Consequently, a few counties have

been chosen to illustrate the variation between strains that was found. In Table 2 the data on six consecutive strains from each of three different counties are presented. Some idea of the extent of the variation within all counties can be obtained from Table 1, where for each character the range from the lowest performing strain to the highest is given.

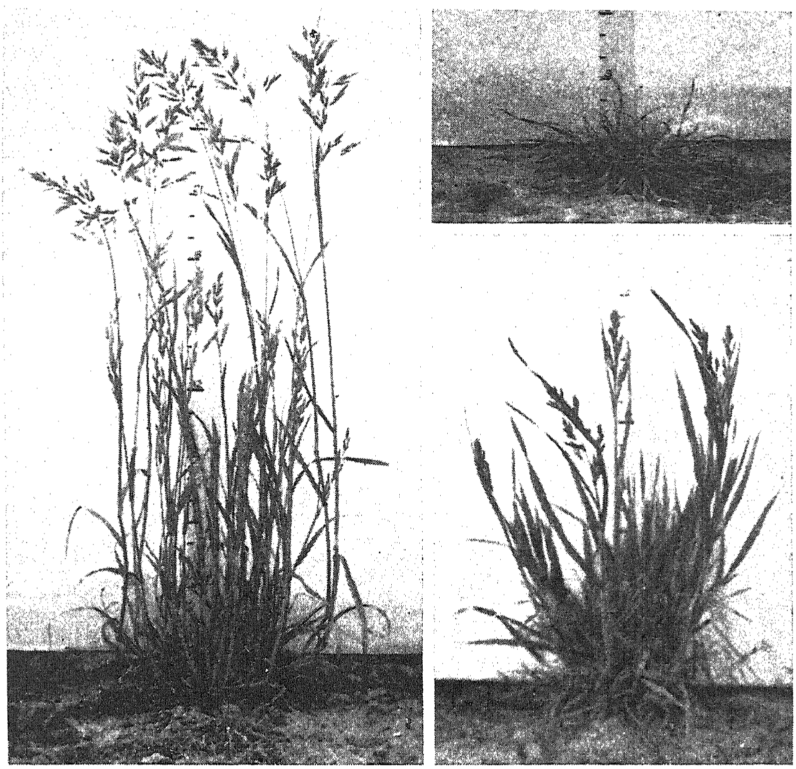

FIG. 1.—Variations in maturity of soft chess, *B. mollis*, from different regions of California and Oregon. *Left*, an example of the early interior ecotype from the Upper Sonoran Zone in Solano County. *Right*, two examples of the coastal or near-coastal ecotype in the Transition Zone, the lower being from Humboldt County, Calif., and the upper from Benton County, Ore. Height scale is in inches.

Table 2 emphasizes that there are differences, sometimes quite wide, in performance among the strains from each county. Sutter County exhibited less variation among its strains than did the other two counties, but even in this county the differences were definite enough to permit the choice of superior strains.

Superior strains have been chosen on the basis of performance for certain agronomic characters. The standard that a strain had to achieve before being selected for further study was: plant weight

TABLE 1.—*Data on plant characters that were obtained from strains of soft chess grown under uniform nursery conditions at Davis, Calif., 1941–42.*

County	No. of strains	Days to head		Plant habit range*	Plant height		Tiller number		Plant weight	
		Mean	Range		Mean	Range	Mean	Range	Mean	Range
Transition Zone										
Benton, Ore.	13	180	166–199	se–sp	73	31–103	28	18–33	18	6–30
Lane, Ore.	3	188	181–202	sp–ssp	74	52–85	23	16–29	16	7–23
Del Norte	16	186	174–201	se–sp	88	58–102	31	22–45	23	7–38
Humboldt	23	174	163–183	e–ssp	77	49–103	27	17–43	23	15–43
Santa Cruz	94 plants	185	169–193	se–ssp	99	68–121	38	12–72	30	—
Mean†	55	180	163–202	e–ssp	80	31–121	28	12–45	21	6–43
Upper Sonoran Zone										
Contra Costa	18	164	155–169	e–ssp	80	72–89	29	20–43	21	14–33
Alameda	10	157	151–164	e–ssp	74	64–87	28	22–36	22	17–32
Monterey	6	160	158–163	e–ssp	81	74–89	25	20–31	23	18–31
Lake	5	164	163–165	e–sp	80	70–86	21	19–22	20	18–23
San Benito	6	156	151–158	e–ssp	78	68–91	25	19–31	22	18–26
Napa	6	158	153–163	se–ssp	77	61–95	27	22–36	20	16–26
Orange	5	152	151–157	se–d	58	52–71	24	20–28	15	12–20
Solano	44	153	151–164	e–ssp	67	55–92	33	23–62	23	14–34
Yolo	9	154	151–160	e–ssp	71	57–86	40	32–49	26	13–36
Tuolumne	2	158	153–162	e–se	90	79–101	27	24–30	36	33–38
Madera	6	159	157–162	e–ssp	83	72–87	24	21–27	20	18–22
Mean	117	157	151–169	e–d	73	52–101	30	19–62	22	12–38
Lower Sonoran Zone										
Sutter	6	151	151	se–sp	60	58–63	35	30–40	25	21–30
Merced	2	154	151–157	se–ssp	64	57–70	24	24	17	14–20
Fresno	6	151	151	sp–ssp	58	55–63	30	28–33	24	22–26
Mean	14	151	151–157	se–ssp	60	55–70	31	24–40	23	14–30

*See page 585 for explanation of letters.
†Santa Cruz material excepted.

TABLE 2.—*Comparisons of strains of soft chess obtained from three different localities in California.*

Strain No.	Days to head	Plant habit	Plant height, cm	Tiller number	Plant weight, grams
		Humboldt County (Transition Zone)			
B322	177	sp	75	32	21
B323	180	se–sp	64	22	15
B324	181	sp	61	24	20
B325	176	sp	88	38	33*
B326	169	se–sp	84	36	33*
B327	180	e–sp	68	32	22
		Solano County (Upper Sonoran Zone)			
B214	153	se–sp	70	27	22
B215	157	e–se	70	35	31*
B216	157	e	71	34	26
B217	152	e–se	71	34	25
B218	157	e–sp	74	37	28*
B219	151	se–sp	62	36	25
		Sutter County (Lower Sonoran Zone)			
B297	151	se–sp	63	40	30*
B298	151	se–sp	58	35	21
B299	151	se–sp	58	35	23
B300	151	sp	63	36	30*
B301	151	sp	58	33	22
B302	151	sp	62	30	22

*These strains are considered superior and will be kept for further test.

28 grams or more; either the height over 90 centimeters or the tiller number over 35. The selected strains in Table 2 are marked. In Table 3 the source of all superior strains of soft chess is listed.

TABLE 3.—*Source of superior strains of soft chess.*

Counties with superior strains	Number of strains		Counties with no superior strains	Total number of strains
	Total	Superior		
Transition Zone			Transition Zone	
Benton, Ore.	13	1	Lane	3
Del Norte	16	4		
Humboldt	23	6	Upper Sonoran Zone	
			Alameda	10
			Monterey	6
Upper Sonoran Zone			Lake	5
Contra Costa	18	1	San Benito	6
Solano	44	9	Napa	6
Yolo	9	4	Orange	5
Tuolumne	2	2	Madera	6
Lower Sonoran Zone			Lower Sonoran Zone	
Sutter	6	2	Merced	2
			Fresno	6

The better-performing strains presented some interesting situations. Selected strains were obtained from all life zones and included types that were both early and late. Better strains seemed to be more prevalent in certain counties than others. Humboldt, Del Norte, Solano, Yolo, Tuolumne, and Sutter counties contributed more than their share of better-performing strains. Solano and Yolo collections were expected to perform well at Davis—which is located on the boundary of these two counties, but the large contribution of these other counties, especially Humboldt and Del Norte, was not anticipated.

Type of fertilization.—A high degree of uniformity existed within each row sown from a single panicle, referred to as a strain in this study. The height and habit, especially, of all plants in each row were very similar. This suggests that soft chess is highly self-fertilized.

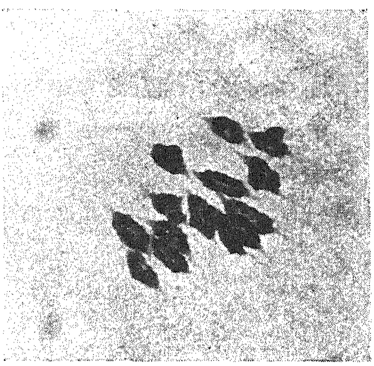

FIG. 2.—Chromosomes (2n = 28) at first meiotic metaphase in a pollen mother cell of soft chess, *B. mollis*.

Cytological variation. — The meiotic process in soft chess is stable and uniform. All 64 investigated strains of this species exhibited the same chromosome number (2n = 28). The chromosomes at first metaphase are illustrated in Fig. 2. There were few departures from the normal meiotic behavior; the mean number of open bivalents was low, and the mean number of univalents was very low. There were a few tetrads with micronuclei.

DISCUSSION

Discussions of the taxonomy of soft chess have assumed this species to be monotypic. No mention has been made of any regional differentiation for physiological or morphological characters. When the panicles of soft chess were collected from the different regions of California and Oregon, it was realized that the maturity of the northern and coastal samples was later than those taken from the interior regions of California. This was considered to be due to the fact that in the coastal and northern areas the season had not advanced so far. It appeared as if soft chess had adapted itself to make its most abundant growth under the warm moist conditions at the end of the winter season. Consequently, it was expected that all strains would exhibit much the same growth rhythm when they were grown under the same environmental conditions.

On the basis of the results from this study, however, soft chess, *B. mollis*, can be divided into two ecotypes, *viz.*, (a) a late coastal or near-coastal ecotype from the Transition Zone along the coast of central and northern California and near-coastal regions of Oregon, and (b) an early interior ecotype from the Upper and Lower Sonoran

Zones of California. The coastal ecotype averaged 180 days to head, whereas the interior ecotype was at least a mean of 20 days earlier, averaging 157 days to head for strains from the Upper Sonoran and 151 days for strains from the Lower Sonoran Zone. The association of lateness with coastal environment is true of other plant species.

Clausen, Keck, and Hiesey (5, 6) found many widespread annual dicotyledonous species to behave like *Layia platyglossa*, exhibiting a later maturity on the coast than in the interior regions of California. Among the perennial herbaceous dicotyledons, Turesson (19) showed an association of lateness with the maritime conditions of western Europe, as contrasted with the earliness of samples from eastern Europe. Unpublished studies by Love of the variation of *Stipa pulchra* in California have shown coastal collections from Santa Cruz County to be later than others.

These ecotypes could not be identified by any other characteristic apart from earliness. The mean plant height decreased from the Transition to the Lower Sonoran Zone, but the variation within the Transition Zone overlapped considerably the variation within the Upper Sonoran. There was no tendency for low-growing types to be more prevalent in coastal and northern collections; the only decumbent types were found in the Upper Sonoran Zone, and sub-erect to sub-spreading types were present in all zones. Clausen, Keck, and Hiesey (5, 6, 7) have generally found in annual and perennial dicotyledons that a prostrate habit is associated with the maritime habitat. Turesson (19) also found this association in perennial dicotyledons from the maritime areas of western Europe. Gregor and Sansome (8) reported prostrate types to be more common in coastal forms of *Lolium perenne* and *Dactylis glomerata*, and Stapledon (16) also found this condition to be true of his collections of *D. glomerata*. In each case, however, the prevalence of prostrate types was related to years of close grazing.

What climatic factor is responsible for this regional difference is not known. Cooler, moister atmospheric conditions that prevail along the coast and even in the more interior regions of Oregon may have effected a genotypical selection of plants that were heritably later and better related to the seasonal rhythm of these areas. Further study will be necessary to determine the correct relation between earliness and environment in these strains.

Within the collections from a single zone, from a single county, or indeed, from a single locality, there were wide variations between strains. This was true of all plant characters. Such a variation is to be expected in a dynamic living world, as Clausen, Keck, and Hiesey (7) have emphasized. This may be even more true of this introduced species than it would be of long-established or indigenous species. Perhaps the perfect relation between climate and plant type in soft chess has not yet been realized in California.

The three zones differed in the range of variation among the strains. Within the Transition Zone there were greater differences between the strains for every character than in the other zones, and the Lower Sonoran showed least variation. This was not only true when the zones were compared as a whole, but even the individual counties

within the Transition Zone showed most variation between strains and the counties of the Lower Sonoran Zone showed least variation. The reason for this cannot be explained satisfactorily. Perhaps the removal of the strains from the Transition to the conditions of the Upper Sonoran Zone has emphasized differences; in other words, the Transition strains might be a more homogeneous population under their own environment. Perhaps the environmental conditions of the Transition Zone are less strict in "fixing" certain types.

The existence of such a wealth of variable types offers favorable material to the plant breeder who is interested in improving this species by selection. Most encouraging is the fact that superior types, as measured by yield, tiller number, and height, have been obtained which differed widely in earliness. It may be possible to introduce a later-maturing strain to regions of California where early-maturing forms now exist and thereby prolong the period of green vegetation without detriment to yield. A reservation must be emphasized at this stage. These selections have been tested under artificial conditions and the results may not agree with those that would be obtained under natural conditions. Further tests must involve seeding experiments under range conditions before any definite conclusions can be arrived at concerning the relation of earliness to yield. These strains have been tested for only one year; critical comparisons of strains require the data of a number of years.

The conclusion from these studies that soft chess is highly self-fertilized is supported by the studies of Troll (17), Beddows (3, 4), and Nilsson (12, 13). Troll considered that cleistogamy was the rule, but Beddows (3) did not find it in his material. No cleistogamous strains were found in the present study. No critical data were obtained to indicate the extent of natural crossing that occurred. Some rows showed an occasional plant that seemed to deviate definitely with respect to earliness or general habit. Beddows (3) concluded that cross-pollination was not impossible, and the wide variation of some individual plants (4) among the progenies of single plants confirmed this opinion. The breeding behavior, then, of this species is most like that in the cereal crops, wheat, oats, and barley. This similarity suggests that breeding methods for the improvement of this species should follow those already practiced among the above-mentioned domestic crops.

There was no variation in chromosome behavior or number with the morphological and physiological variation of soft chess. The meiotic behavior of all strains was regular and uniform and the chromosome number was 28 (2n). This would indicate that the variation within this species could be related to genic differences. Clausen, Keck, and Hiesey (7) found a similar situation in *Potentilla glandulosa*. The tremendous range of variation within this species in California was associated with a constant chromosome number ($2n = 14$).

Studies of the ecological response of annual grasses or annual herbaceous dicotyledons under natural conditions are extremely limited. Turesson's studies (18) on the distribution of the ecotypes of the annual *Atriplex* species did not include comparisons of a species

under both maritime and inland habitats. A more complete account of the investigations by Clausen, Keck, and Hiesey upon the annual *Madiinae* is awaited with interest. It seems to the writer that annual plants have not been exploited enough in studies of the relationships between natural populations and climate. Annual grasses, in particular have been ignored almost completely. Annuals are at a disadvantage in transplant experiments; studies would have to be limited to seedings. If the species were cross-pollinated, there would be the difficulty of maintaining "pure" seed stocks. Where self-fertilization is the rule, however, annual species have certain advantages. They usually produce abundant seed, and seed stocks could be built up quickly and could be easily maintained. They complete their life cycle in one year and experimental technic would be speeded up.

A possibility is seen of the annuals serving a valuable role in determining the dynamic nature of the different ecotypes, where ecotypes are available. If it were highly self-fertilized and where readily distinguishable character-differences between ecotypes were available, an annual species could be used under different environments to picture the competition between ecotypes. Harlan and Martini (10) have related the distribution of barley varieties in the United States to the competitive success of the same varieties in varietal mixtures grown in the different barley regions. A similar test could be conducted under more or less natural conditions to compare the competition of ecotypes in ecotype mixtures when they are grown in different ecologic regions.

SUMMARY

1. Panicle selections of soft chess, *Bromus mollis*, from California and Oregon were grown under uniform nursery conditions and studied to determine the morphological, physiological, and cytological variation.

2. Distinct regional differences were shown to exist for time to head but not for any other character. An early maturing interior ecotype and a later coastal ecotype were demonstrated.

3. Each strain appeared very uniform and distinct from the other strains, suggesting that this species is self-fertilized.

4. Within collections from the same county and from the same locality wide differences were found in the morphological appearance and physiological behavior of the separate strains.

5. Cytologically, soft chess is very uniform among strains, there being no departure from the condition of 28 chromosomes (2n) and no evidence of consistent abnormalities in the meiotic process.

6. Annual species, where ecotypes exist and where they are self-fertilized, are suggested as being of possible value in studies of the dynamic nature of the ecotype.

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REDUCING THE ERROR IN INFILTRATION DETERMINATIONS BY MEANS OF BUFFER AREAS[1]

F. L. Duley and C. E. Domingo[2]

INVESTIGATORS interested in the use, disposal, or storage of rainwater have made many attempts to estimate field infiltration rates by means of artificial applications of water to small plots. Different types of equipment and methods have been employed for the purpose. The size of the areas to which water has been applied has varied from a few square inches to several hundred square feet. The methods of applying water have varied from irrigation by flooding with a constant small head over the entire surface to various methods of sprinkling, using a wide range of intensities and size of drops. Certain fundamental principles concerning the relative importance of various surface factors which may affect the rate of intake have been ascertained through the use of these small areas.

The results of most infiltration tests as determined by the use of small areas indicate the capacity of the surface to transmit water under different conditions of soil or surface cover. This information has been of great value, but the infiltration rates obtained do not necessarily represent the absorption that would occur during rainfall. With small areas such as those where tubes have been driven into the ground, or even with small or narrow plots, there may be so much lateral seepage beneath and beyond the plot boundaries that the indicated intake is much higher than would occur over an entire watershed under rainfall conditions. Excavations across small plots after water has been applied for a few hours have shown that the wet soil tends to assume an irregular elongated, globular shape, and may have a mean horizontal cross section several times as large as the plot itself.

Katchinsky (1)[3] attempted to calculate the true permeability of a soil from the extent of the wetted material below and beyond the plot boundaries. Several other investigators (2, 3, 4, 5) have sought to avoid the error in infiltration rates due to lateral seepage by increasing the width or area of the plot or by using concentric areas or multiple square areas where only the inner rings or squares are used for determining intake rates. In some plot tests a larger area has been sprinkled than the plot on which the infiltration measurements have been made. Any of these methods may serve to reduce the variability between duplicate tests, but probably cannot eliminate the fundamental error due to subsurface lateral seepage from any small plot of whatever shape even though it may be several feet in its narrowest dimension.

When water is applied to a small or narrow plot on land that is not saturated, the water descends into the soil as an expanding

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[2]Senior Soil Conservationist and former Cooperative Agent, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 605.

hydraulic wedge. The water pushes the air laterally and moves in to take its place. The air may continue to move laterally under slight pressure or escape to the surface through soil pores or vents. As more water is applied, the volume of wet soil continues to be extended downward and sidewise. The interfacial boundary between this saturated soil and the surrounding soil of lower moisture content can continue to expand in all directions, and thus allow more water to enter through the limited area to which water is applied than would be possible if the water could not move laterally as soon as it is below the surface. Under natural conditions where rain is falling over an entire watershed, the water must pass directly downward into the soil, since extensive lateral movement is prevented because moisture penetration will be at about the same depth over the entire area. Entrapped air can escape only vertically through the soil pores or other vents that may be present in the soil. Since space for extra water cannot be made by sidewise movement, the total amount absorbed as well as the rate of intake will be very much lower when it is raining over the entire surface than when water is applied to small plots.

In the work herein reported, an attempt was made to eliminate the lateral movement of water in infiltration tests, and thereby make possible the determination of infiltration rates more closely in agreement with the rates under rainfall conditions than are now possible through the use of any type of small plots.

METHODS

THE SOIL

The soil on which these tests were conducted is a Marshall silty clay loam (heavy subsoil phase). The test site was a 4.6% slope located on a vacant lot on the outskirts of Lincoln, Nebr., close to the city water supply. The soil was relatively dry at the time of the tests, August and September, 1941. The land was in wheat in 1941 but had been used for truck crops most of the time for several years.

PROCEDURE FOR LARGE PLOTS

Three approximately square plots, each 0.016 acre in area, were laid out on the slope mentioned above. Two opposite corners of a plot were placed on the contour, thus making the other two corners fall in line with the slope. This plot was surrounded with 9-inch strips of sheet metal sunk into the ground to a depth of 6 inches, allowing a 3-inch extension above ground which separated the runoff water within the plot area from that falling outside the plot.

In order to guard against subsurface lateral seepage below the plot boundaries and the loss of some water from the plot area, a saturated buffer zone of soil was put down surrounding the plot. The saturation of this area was accomplished by digging a trench about 4.5 feet outside the plot boundary (Figs. 1A and 2x) entirely around the plot, which left an area between the plot boundary and the buffer zone that received the same treatment as the plot itself. Baffles were placed in the bottom of the trench, and it was then filled with straw to maintain a high intake rate. Water was run through the trench for about 48 hours, after which the straw was removed and the trench filled with soil. This watering had wet the soil in a belt about 7 to 10 feet deep and 3 to 5 feet wide completely around

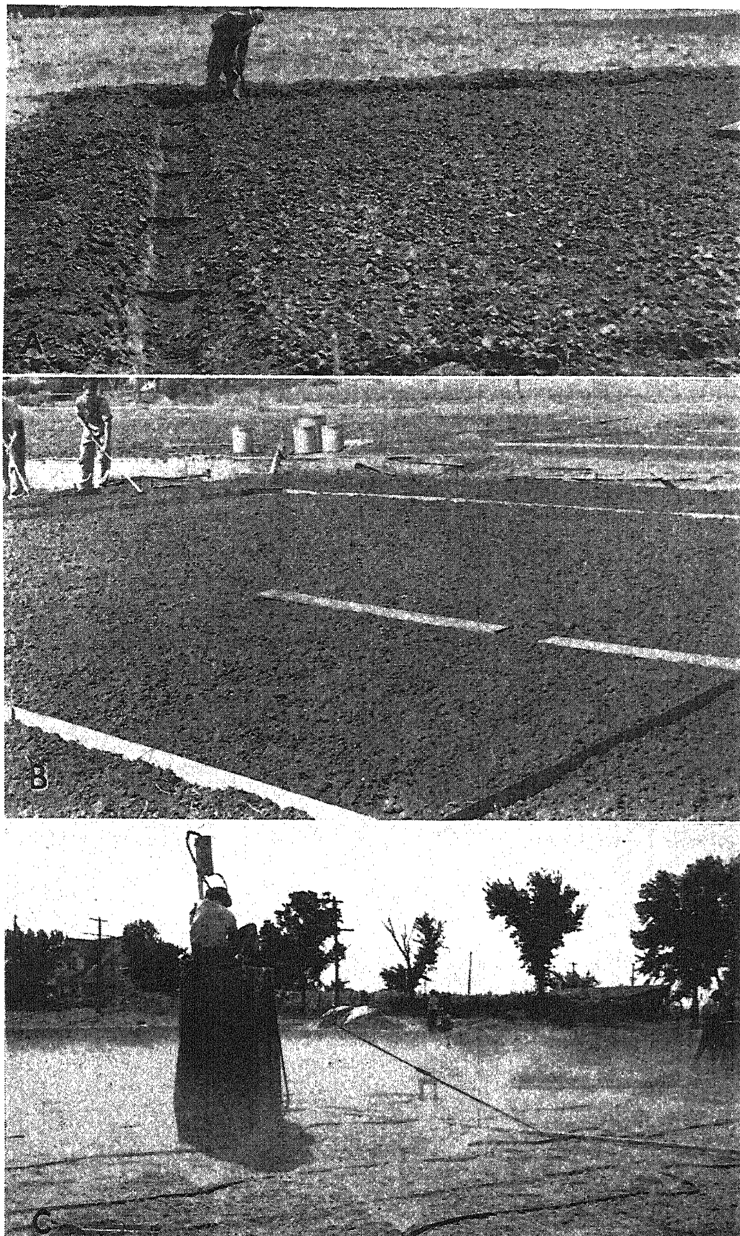

FIG. 1.—Preparation and operation of large plots. A, trench around plot for wetting border; B, condition of surface before straw was applied; C, arrangement of nozzles showing hose connection and type of water distribution. Small plot in center is also shown.

the plot. This saturated soil was equivalent to putting down a wall of water through which soil air would hardly pass. The colloidal material of the soil had sufficient time to swell until water would not pass rapidly through this wet zone.

The soil of the plot was then spaded to a depth of 5 inches and worked down to a seedbed condition (Fig. 1B). The area outside the plot boundary and beyond the trench from which the buffer zone was wetted was similarly treated, the total spaded area being 0.04 acre. This entire area was covered with straw at the rate of 4 tons per acre (Fig. 1C). Previous tests indicated that this amount of straw permitted the maximum intake of water.

In order to sprinkle these plots at the high rates desired, an ample supply of water was obtained from a city fire hydrant. A water meter was set between the source of water and the sprinkling equipment, which consisted of an iron supply pipe to which was attached 30 stationary nozzles by means of rubber hose. One row of these sprinklers (Fig. 2N) was placed outside and completely around the 0.016-acre plot (Fig. 2abcd), which was used for determining the infiltration rate. This ensured a uniform distribution of water over the entire area of this plot. At the same time the land outside the 0.016-acre plot and extending beyond the pre-wetted buffer belt was kept wet by this outside line of nozzles.

These nozzles threw the water upward in a spray having a morning glory shape. Even though each sprinkler distributed the water in a circular area, the overlap was adjusted so that there was a reasonably even distribution of water over the entire area. Since there was a heavy straw cover on the plots, there was less necessity for extreme uniformity of distribution of water over the surface than would be the case if the soil were bare.

The application of water was made during early morning or late afternoon when the rate of evaporation was as low as possible, so that this factor would introduce no important error in the final results. The rate of application varied during the first test on the three large plots from about 3.7 to 4.2 inches per hour. The first application was for 1.5 hours. The second and third applications were each for 3-hour periods and the rate was maintained well above the rate of intake so that there was considerable runoff during most of the time of the second and third tests.

The runoff from the 0.016-acre plot drained out through an opening at the lower corner and was carried down the slope through a 3-inch glavanized iron pipe (Fig. 2–O). The runoff water was caught in a bucket and then measured by pouring into a large calibrated can. Readings were taken at 200-second intervals, so that the difference between application and runoff could be calculated and the infiltration curves plotted.

SMALL PLOT PROCEDURE

For comparison of infiltration measurements on small plots in comparison with the large ones, a small plot procedure was employed that had previously been used extensively on this project for studying the effects of surface condition and surface protection on intake of water. A rectangular open frame, 16 by 72 inches, was set in the ground to a depth of 9 inches with 3 inches extending above the surface, except at the lower end which was cut out so that it was level with the ground surface. On top of this frame was placed a rectangular metal windbreak extending 6 feet vertically above the box.

For sprinkling this small plot, water was forced by air pressure from a metal tank to a small constant-level supply can placed about 3 feet above the top of the

windbreak (Fig. 1C). A rubber hose attached to the botton of this can was provided at the lower end with a small sprinkler nozzle. By manually swinging this nozzle back and forth, with some widewise shaking, a relatively uniform distribution of water could be obtained.

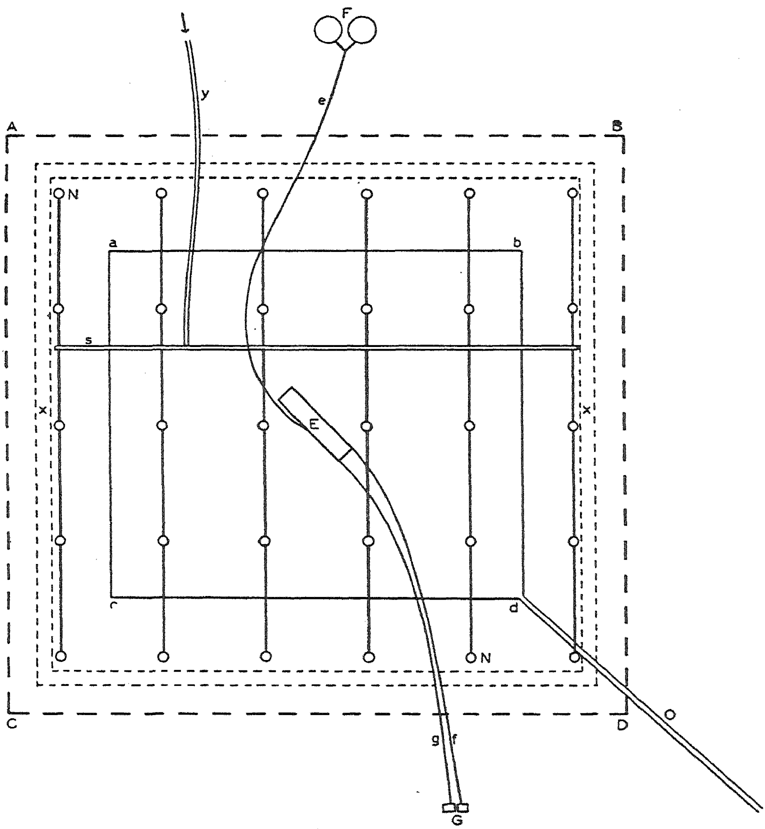

FIG. 2.—Diagram of field plot. abcd, plot 24.53 × 28.4 feet from which runoff was measured, bc on contour; x, trench for wetting buffer zone; y, hose from fire hydrant; s, iron supply pipe; N, sprinkler nozzles connected by rubber hose to supply pipe; E, small plot located inside plot abcd; e, hose from supply tanks F to small plot; g and f, hose for runoff and waste water from small plot E; G, collecting cans; O, pipe to carry runoff from plot abcd to measuring can; ABCD, boundary of entire wetted area. Scale 1 inch = 13.2 feet.

Any water striking the sides of the windbreak was caught in a small gutter and drained away through a small outlet tube at the lower end of the plot, where this waste water was collected and measured. The water running off the plot itself emptied into a small gutter attached to the lower end of the frame at ground level. From here it was carried through a tube to a small container where it was collected and measured. All measurements were taken at 200-second intervals, which made it possible to plot curves showing the rate of intake throughout the course of a test.

The intake of water by these small plots was compared with that of the large ones, using the procedure already described for each type of plot. The comparative intake was determined for two sets of conditions. In one case the small plots were in the open field away from the large plots with no precautions taken against subsurface lateral seepage of water beyond the bounds of the small plot. The other condition was with the small plot set in the middle of the large plot (Fig. 2E) and the application of water made simultaneously to each. In this case it was assumed that the water would penetrate below the small plot at the same rate as on the large plot, and therefore lateral movement of water from beneath the small plot would not take place. In each case the soil condition and cover used were identical with that of the large plots.

RESULTS

The total intake and the infiltration rate at the end of each test period are given in Table 1. The first test, which was for 1.5 hours, produced no runoff on any of the plots and served mainly for bringing the plots to a similar degree of wetness so that runoff might take place the more readily at the next run.

TABLE 1.—*Intake of water on large and small plots and final intake rates in inches per hour, August–September, 1941.*

Plot	Intake, surface inches				Final rate of intake, inches per hour		
	Test 1, 1½ hrs.	Test 2, 3 hrs.	Test 3, 3 hrs.	Total	Test 1, 1½ hrs.	Test 2, 3 hrs.	Test 3, 3 hrs.
Large Plots with Wetted Borders							
L3	5.64	5.06	3.84	14.54	3.75	1.10	0.70
L4	6.42	2.89	2.39	11.70	4.25	0.45	0.35
L5	5.44	5.26	3.32	14.02	3.65	1.05	0.70
Mean	5.83	4.40	3.18	13.42	3.88	0.87	0.58
Small Plots Inside Large Plots							
81*	5.55	4.19	3.88	13.62	3.50	1.00	0.75
82†	5.72	2.93	2.15	10.80	3.80	0.30	0.25
Mean	5.64	3.56	3.02	12.21	3.65	0.65	0.50
Small Plots Without Wetted Borders in Open Field							
83	5.17	10.32	7.08	22.57	4.00	3.15	2.00
84	6.02	9.54	8.82	24.38	4.00	3.00	2.70
Mean	5.60	9.93	7.95	23.48	4.00	3.08	2.35

*Inside plot L3.
†Inside plot L4.

During the second and third runs, water was applied at rates well in excess of intake. Therefore, the amounts of water absorbed during these runs represent the maximum capacity of the soil to absorb water under the conditions employed.

In the case of the large plots, there was considerable spread between the absorption on plots L3 and L4, but plot L5 was in very

close agreement with plot L3. This might raise a question as to the number of such plots needed to obtain a satisfactory determination of intake capacity of a given soil. It would seem reasonable that the degree of accuracy should be increased by use of the large plot, but there is often difficulty in finding large areas that are as uniform in all respects as would be desired. Such lack of uniformity may have been one reason the absorption by L4 was lower than had been expected.

If the results obtained on the small plots, 81 which was within L3, and 82 which was within L4, are considered, there is good agreement between the large and small plots in each case. The total intake of L3 was only about 6.7% greater than for 81, and the intake of L4 was 8.3% greater than for the small enclosed plot 82. This shows that by giving the small plots the protection of the surrounding soil water of the larger plots, approximately the same results were obtained on each.

The small plots in the open field away from the large plots gave widely different results from either the large plots or the enclosed small ones. The mean total intake of water for the three application periods was 75% higher on the small plots in the open field than on the large plots protected with a buffer strip and a saturated belt of soil, and 92% greater than for the small enclosed plots. These results clearly indicate that much water had escaped from beneath the small plots in the open by subsurface lateral seepage, and the results were accordingly much higher than on the large or small plots where the water had been forced to go directly downward into the soil.

The infiltration curves for one large plot, L3, and for the mean of the two small plots 83 and 84 in the open field, based on intake measurements taken at 200-second intervals, are shown in Fig. 3. Curves A and D really represent only the rates of water application, since there was no runoff. The infiltration capacity of the soil at that time was therefore higher than the position of these curves indicate. The infiltration curves B and C for the large plot are lower throughout and come to a substantially constant value at a much lower point than do curves E and F, representing rate of intake by the small plots in the open field. This indicates that the water on the small plots was escaping from beneath the plots at approximately a constant rate, which enabled more water to be taken in at the surface than on the large plots where the water was forced to go directly downward.

The soil moisture to a depth of 10 feet before and after the tests on the large plots L3 and L4 were made is shown in Table 2. The data showing the moisture after sprinkling were obtained as the mean of three cores on each plot. This accounts for the apparent tapering off of moisture in the 7- to 9-foot zone, since the moisture had not penetrated to the same depth in all sample locations. If it had done so, the break in moisture would have been abrupt, since water moving downward into a dry soil tends to advance as a front. It is to be noted that there was no increase in moisture in the tenth foot.

By converting the percentage increase in soil moisture after watering to surface inches, it was indicated that 12.45 inches had been stored in this soil. The water meter readings of the amount of appli-

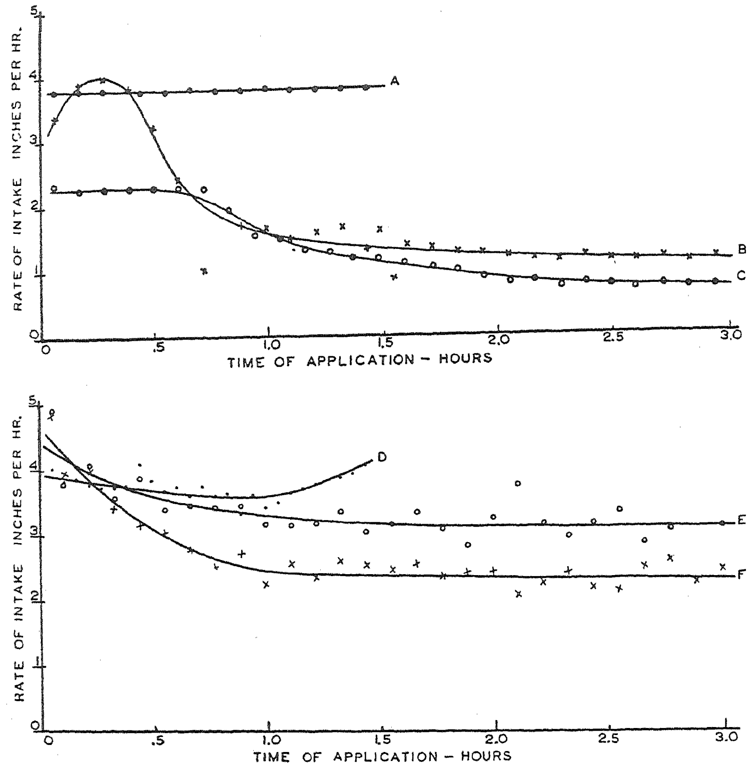

FIG. 3.—Infiltration curves. *Above*, large plot L3, A, first test, no runoff; B, second test; C, third test. *Below*, small unprotected plots, D, first test, rise in curve at end due to increase in application, no runoff; E, second test; F, third test.

TABLE 2.—*Soil moisture content at time of tests, percentage moisture on basis of dry soil.*

Plot	Depth, feet									
	1	2	3	4	5	6	7	8	9	10
				Before Sprinkling						
Field area L3 and L4...........	12.4	15.3	15.6	15.9	16.4	16.9	17.7	17.3	17.2	16.7
				After Sprinkling						
L3.............	29.4	27.6	25.0	23.6	24.0	24.3	22.9	20.8	19.6	16.7
L4.............	33.3	27.9	24.9	25.0	25.7	22.6	21.6	19.9	19.1	16.5
Mean...........	31.3	27.7	24.9	24.3	24.9	23.4	22.3	20.3	19.4	16.6
Increase, %......	18.9	12.4	9.3	8.4	8.5	6.5	4.6	3.0	2.2	−0.1
Increase, surface inches*........	2.97	2.18	1.73	1.45	1.46	1.07	0.76	0.49	0.36	−0.02

*Total surface inches increase 12.45.

cation, minus the amount lost in the runoff, indicated that 13.12 inches had been absorbed by plots L3 and L4. This close agreement indicates that water must have gone directly downward into the large plots and that none had been lost by lateral movement of water within the soil.

DISCUSSION

Since large plots surrounded by a buffer watered area and also by a prewetted belt gave results indicating that applied water had gone directly downward in the soil and none had been lost by lateral seepage, it appeared that the intake closely represented the intake possibilities of the soil. The results should approximate the possibilities for intake under natural conditions, were it raining over an entire watershed where soil and surface conditions were the same as used in these tests. The results appeared to be much more accurate than the larger amounts of intake on small plots in the open field without protection from lateral seepage. For any hydrologic work where total intake capacity of watersheds is desirable, it would seem that determinations made by the large plot method would be much more directly applicable.

So far this method has been used on only a single soil, but since it appears to give results approaching maximum intake capacities, it might be of much value to have such determinations for a wide range of soils.

There are certain disadvantages in the use of the large plots as compared with the small ones, in that tests are more difficult to make. It is often difficult to select a group of large plots where the soil conditions are as uniform as would be desired. More time and labor are involved, and the original cost of equipment may be somewhat higher, however, this is not excessive. Since large quantities of water are necessary, it is desirable to locate near a large water supply, such as a city water main or a clear water reservoir. The sprinkling equipment used in these tests would not be entirely suitable for testing bare soils, since the water was not thrown very high and the impact of the drops would be too small. Also, the distribution of water in circular areas was probably not as uniform as would be desired for bare soils. Furthermore, the type of large plot used in these tests will probably have its greatest value in determining maximum intake capacity of soils, since it is during such tests that small plots give their greatest error from subsurface lateral seepage.

In these tests only one size of large plot was used, and therefore it is not yet possible to say what minimum size would be possible for satisfactory results if provision were made to avoid lateral seepage. The small plots inside the large ones gave results comparable with those of the large plots, but methods have not yet been devised for adequately protecting the small plots against lateral seepage when a large wetted area is not used to surround it.

The small infiltrometer has been extensively used by many investigators and much valuable information has been obtained with it, particularly with regard to evaluating the effect of different surface conditions or types of residue on intake of water by the surface

soil. Since the use of small areas permit so much loss of water by lateral seepage, the principal information obtained from the use of this type of equipment is confined to surface phenomena. Such tests show the capacity of the surface to transmit water rather than the rate at which water might be absorbed by the soil profile during rainfall. If the use of the small unprotected infiltrometer is confined to this limited field and not used for determining intake capacity, it has possibilities of yielding much additional information.

SUMMARY

A method is described for determining the infiltration capacity of a soil by using large plots protected against loss of applied water through lateral seepage.

Approximately square 0.016-acre plots were laid out on a 4.6% slope and surrounded by metal borders sunk into the ground to a depth of 6 inches. Surrounding the plot was a border space which had the same treatment as the plot itself. About 4.5 feet outside the plot lines a trench was dug and water run through this until a belt of soil 7 to 10 feet deep around the plot was saturated. This served as a buffer area through which water and air could not pass laterally from the plot area on which infiltration tests were to be made.

The plot together with the border area was spaded and covered with straw and then sprinkled by means of a multiple set of stationary sprinklers. The runoff from the 0.016-acre plot was collected and measured, and the total intake and infiltration rate determined.

A small plot, 16 by 72 inches, was placed in the middle of the 0.016-acre plot area and given the same preparation and straw treatment. The application of water and runoff were determined by a special system entirely separate from that used on the large plot.

The results show that the intake of water on the large plots and on the small plot within were similar.

Other of these small plots were placed in the open field where they had no water applied to the surrounding soil and no wet buffer belt to prevent lateral movement of air or water.

The intake on these isolated small plots having no prewetted border protection was 75% greater than for the large plots. These results indicated that lateral movement of water had allowed these small plots to take in more water than would be possible if it were raining over the entire surface.

Since the large plots were protected against lateral movement of water beneath the surface, the results on these plots should represent about what would be the intake possibilities if rain were falling over an entire watershed having the same soil and surface conditions as did these plots.

The method used on these large plots might provide a means for determining with a fair degree of accuracy the infiltration capacities of a wide range of soils and surface conditions under natural rainfall.

The method might be made to supplement the use of small plots when total intake capacities rather than the effect of specific surface treatments on intake are desired.

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COMPETITION IN COTTON VARIETY TESTS[1]

T. R. RICHMOND[2]

IN DESIGNING experiments to test the yields of varieties of cotton, it is important to know to what extent intervarietal competition may be expected to affect the yields of the varieties. Intervarietal competition either has been found by test or assumed in many field crops, and the effect of the competition in yield trials of these crops has been eliminated by protecting the plot area to be harvested with border plantings of the same variety. If it can be demonstrated that the effect of the intervarietal competition in cotton is not significant, no precision in testing will be gained by protecting the plot area to be harvested with border rows. Under such conditions the width of the plot may be reduced to a minimum or a single row. On the other hand, if cotton varieties differ in their ability to compete, a bias resulting from intervarietal competition will be introduced in tests in which single-row plots are used. Even if some intervarietal competition can be demonstrated, the lower experimental error expected when single-row plots are used, as compared to the experimental error of tests employing multiple-row plots in which more than one row is harvested for yield, may increase the precision of the test as much or more than the elimination of competition between varieties through use of border rows. Furthermore, the additional area occupied by multiple-row plots adds considerably to the expense of conducting a variety test.

Investigators who have worked on this problem are not in full agreement as to the effects of intervarietal competition on variety tests of cotton. Christidis (1)[3] from experiments at the Greek Cotton Institute found significant differences between varieties grown in adjacent, unprotected rows and concluded that, "The results . . . . seem to suggest that competition may cause a definite bias in estimating the comparative yielding value of cotton varieties."

Quinby, Killough, and Stansel (3) conclude from studies at three locations in Texas that, ". . . . cotton varieties differ but little in ability to compete, that varieties compete the same in a favorable as in an unfavorable season, and that single-row plots can safely be used."

Hancock (2), in Tennessee, conducted an experiment with two varieties of cotton, California Acala and Delfos 6102, which, from previous trials, appeared to differ considerably in plant growth. The two varieties were arranged in single-row plots in such a way

[1]Contribution from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Texas, and the Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Technical paper No. 690, Texas Agricultural Experiment Station. Received for publication April 1, 1943.

[2]Associate Agronomist, Bureau of Plant Industry, and the Texas Agricultural Experiment Station. The author acknowledges the assistance of Mr. Charles F. Lewis, Agent, and Roy E. Harper, formerly Junior Botanist, Bureau of Plant Industry, in statistical calculations.

[3]Figures in parenthesis refer to "Literature Cited", p. 612.

that a given variety received three possible border effects, i. e., bordered on each side by the same variety, bordered on one side by the same variety and on the other side by the other variety, and bordered on both sides by the other variety. For a single season no significant differences were observed among the Delfos combinations, but the Acala combinations differed significantly in most instances. He reported an apparent additive factor for plant competition when averages for the 4 years of the test were considered. On medium fertile soils single-row plots bordered on one side by an unlike variety differed but little from similar plots bordered on both sides by the same variety, and it was suggested that two-row plots be used in trials on such soils.

The results of an experiment to determine the intervarietal competition between varieties of cotton grown on alluvial soil in the Brazos River Valley, near College Station, Texas, are given in this paper, together with an analysis of intervarietal competition from cotton variety test data taken by workers at the U. S. Cotton Field Station, at Greenville, Texas.[4]

DESIGN AND PROCEDURE

Using data from previous variety tests as a basis for selection, two early-maturing and two late-maturing varieties were chosen for the experiment conducted in the Brazos River Valley in 1940. The early varieties were designated as E_1 and E_2 and the late varieties as L_1 and L_2. The greatest opportunity for intervarietal competition should occur when a single row of one variety is bordered on both sides by rows of another variety, as $L_1E_2L_1$. Conversely, there should be no opportunity for intervarietal competition when a single row is bordered on both sides by the same variety, as $E_2E_2E_2$. Therefore, the experiment was designed to determine the effect of intervarietal competition on the middle row of three-row plots when each of the four varieties was grown between border rows of each of the four varieties in the test. Thus, the experiment was adaptable to factorial analysis. The 16 possible combinations of middle rows and border rows in three-row plots were as follows:

Middle row—E_1	Middle row—L_1
$E_1E_1E_1$	$E_1L_1E_1$
$E_2E_1E_2$	$E_2L_1E_2$
$L_1E_1L_1$	$L_1L_1L_1$
$L_2E_1L_2$	$L_2L_1L_2$
Middle row—E_2	**Middle row—L_2**
$E_1E_2E_1$	$E_1L_2E_1$
$E_2E_2E_2$	$E_2L_2E_2$
$L_1E_2L_1$	$L_1L_2L_1$
$L_2E_2L_2$	$L_2L_2L_2$

The three-row plots were randomized within blocks and were replicated six times. The length of plot used was 50 feet. The row width was 40 inches, the width commonly used in commercial plantings in the Brazos River Valley.

[4]The data from the U. S. Cotton Field Station, Greenville, Texas, were made available to the author through the courtesy of D. R. Hooton, Superintendent.

The seeds were planted with an ordinary horse-drawn cotton planter. Good stands were obtained. The usual production methods common to the region were used in thinning, leaving two or three plants per hill at intervals of 8 to 10 inches. Each row of each plot was picked separately and the yield of seed cotton was recorded to an accuracy of 1/10 pound.

The cotton variety tests at the U. S. Cotton Field Station, at Greenville, Texas, from which data were used in this paper, were laid out in four-row plots, 100 feet long, with a minimum of eight replications. The variety tests for 1934, 1936, and 1937 were designed as randomized blocks and the regional variety study for 1936 and 1937 as double restricted latin squares. In this study the regional variety test data were analyzed as randomized blocks.

RESULTS

BRAZOS VALLEY EXPERIMENT

Since both of the border rows of each plot were the same variety, the yield of the middle row should measure the net effect of intervarietal competition within a single plot. Table 1 gives the total yield of the six replications of each border-middle row combination and the average border and middle-row variety effect. The effect of a given border treatment will be found by adding the yields of the middle rows of the four plots in each block in which the border treatment occurs. Reference to Table 1 will show that each variety occurs in the middle row once and only once in plots of the same border treatment, thus allowing comparisons between border treatments. The yield of a given variety will be found by adding the yields of the middle row of each plot in which the variety occurs, in which case each border treatment occurs once and only once with the variety.

TABLE 1.—*Yield of middle rows of three-row plots expressed as totals of six replications and averages of 24 plots.*

Bordered by	Variety				Total	Mean of 24 plots
	E_1	E_2	L_1	L_2		
E_1	27.1	28.7	13.9	27.7	97.4	4.06
E_2	23.0	29.4	13.5	21.9	87.8	3.66
L_1	28.4	30.5	16.8	26.2	101.9	4.25
L_2	25.4	29.3	14.7	27.5	96.9	4.04
Total	103.9	117.9	58.9	103.3	384.0	—
Mean of 24 plots	4.33	4.91	2.45	4.30	—	—

It was determined from previous trials that the four varieties used in this experiment differ significantly in yield. Our problem was to determine, under these conditions, the effect of varieties grown as borders on varieties grown between borders. Table 2 gives a gross analysis of these effects and separate comparisons for the main effects of border varieties and middle-row varieties. There was a highly significant border effect showing that there was definite competition among the different border and middle-row variety combinations, or

that the middle rows responded differently to the different border treatments. In the separate border variety comparisons based on a single degree of freedom, the rows bordered by early varieties differed significantly from those bordered by late varieties. There also was a significant difference between the two early border varieties, but there was no difference between the late border varieties. All middle-row variety comparisons gave significant differences. The absence of a significant border×variety interaction indicates a relatively consistent behavior of the four middle-row varieties with respect to the different border treatments.

TABLE 2.—*Analysis of yields of middle rows of three-row plots using four varieties each with four border treatments.*

Variation due to	D.F.	Sum of squares	Mean square	F
Border effect	3	4.3675	1.4558	5.34*
Individual comparisons:				
E_1+E_2 vs. L_1+L_2	1	1.9267	1.9267	7.07*
E_1 vs. E_2	1	1.9200	1.9200	7.05*
L_1 vs. L_2	1	.5208	.5208	1.91
Middle-row variety	3	82.1550	27.3850	100.50
Individual comparisons:				
E_1+E_2 vs. L_1+L_2	1	37.0017	37.0017	135.79*
E_1 vs. E_2	1	4.0833	4.0833	14.99*
L_1 vs. L_2	1	41.0700	41.0700	150.72*
Border × variety	9	3.3609	.3734	1.37
Blocks	5	9.8150	1.9630	7.20
Error	75	20.4416	.2726	
Total	95	120.1400		

*Exceeds P .01.

The results obtained show that there was competition among the four varieties used and it seems reasonable to assume that some bias would have been introduced into an experiment composed of single-row plots of the same varieties.

The design of the experiment was such that comparisons were made between early and late maturity, but it appears that a better comparison would have been between high yield and low yield, since E_2, the highest variety in yield, also was the greatest competitor, and L_1, the lowest yielding variety, was the poorest competitor. Varieties E_1 and L_2 were approximately equal both in yield and competitive ability. The experiment suggests a strong association between the yield and the competitive ability of the cotton varieties.

GREENVILLE EXPERIMENTS

As the varieties used in the Brazos River Valley experiment were chosen arbitrarily to represent somewhat extreme types of plant growth, and as the border rows of each plot were of the same variety, opportunities for intervarietal competition would be greater in such

a test than in one composed of a larger number of varieties representing gradations in yield and plant type. Tests for intervarietal competition may be made in experiments primarily designed for testing yields of a number of varieties provided the plots are composed of three or more rows and are properly randomized.

In 1934, 1936, and 1937 the variety tests at the U. S. Cotton Field Station, at Greenville, Texas, were designed as complete randomized block experiments with four-row plots 100 feet long. The yields of each row of each plot were recorded separately. Individual row data for 1935 were not available. Data from another test grown in 1936 and 1937 and known as the regional variety study also were available for similar analysis. Since the individual plots consisted of four rows, the data were adaptable to a split plot analysis in which the sum of the yields of rows 1 and 4 represented a variety under competition and the sum of rows 2 and 3 represented the variety without competition. In the regular station variety test, 11 varieties were grown for the 3-year period. The regional variety study was made up of 16 varieties representing types from the main regions of the cotton belt.

The essential elements of the analysis of the data from the Greenville experiments are given in Tables 3 and 4. The variance due to *position* measures the over-all effect of the sum of the outside rows compared with the sum of the inside rows without regard to variety. The *variety×position* interaction measures the varietal response to the two possible positions or the intervarietal competition. The *variety×position* interaction was tested by the remainder variance or general error and the *position* effect was tested by the *variety× position* interaction.

The analysis of the data from the regular variety test for the three separate years and for the three years combined is given in Table 3. No significant values were obtained from the 1934 data, a condition probably due to general low yields. In 1936 and 1937 the *variety× position* interactions were significant though barely so at the P.05 level in 1936. The *position* effect was significant at the P.05 level in 1936 and at the P.01 level in 1937. In the combined analysis all of the elements tested gave significant values. The significant *variety× position×years* interaction indicates a difference in the intervarietal competition in the different years.

TABLE 3.—*Analysis of variety tests at Greenville, Texas.*

Sources	1934		1936		1937		Combined	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
Years×position	—	—	—	—	—	—	2	4.5480
Position*	1	0.5128	1	4.5184	1	24.0796	1	20.0148
Variety×position	10	0.5959	10	0.6184	10	1.7220	10	1.4493
Variety × position × years	—	—	—	—	—	—	20	.7435
Error	77	0.3451	77	0.3248	77	0.5722	231	.4140
Total (split plot)	88	—	88	—	88	—	264	—

*Sum of the two outside rows compared with the sum of the two inside rows.

The analysis of the regional variety study, shown in Table 4, gives essentially the same information. The *variety×position* interaction was nonsignificant in 1936, and significant in 1937 and in the combined analysis. The *position* effect was significant in 1936, nonsignificant in 1937, and significant in the combined analysis. The variance for *years×position* and for *variety×position×years* interaction was not significant.

TABLE 4.—*Analysis of regional variety study at Greenville, Texas.*

Sources	1936		1937		Combined	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
Years×position	—	—	—	—	1	0.0508
Position*	1	4.8675	1	3.5627	1	8.3794
Variety×position	15	0.4646	15	1.9992	15	1.4768
Variety×position×years	—	—	—	—	15	0.9870
Error	112	0.2960	112	0.9370	224	0.6165
Total (split plot)	128	—	128	—	256	—

*Sum of the two outside rows compared with the sum of the two inside rows.

In both experiments there was, as an average of all varieties, a significant difference between the yields of the outside and the inside rows, the difference being in favor of the outside rows. The reason for the generally higher yields of the outside rows is not apparent from the data and no explanation is offered here. Regardless of the general tendency for the outside rows to yield more than the inside rows, there was a significant *variety×position* interaction which is taken as evidence of intervarietal competition.

In these experiments, as in the Brazos River Valley experiments, there was a definite tendency for the higher yielding varieties to be the strongest competitors.

DISCUSSION

Since evidence of intervarietal competition was found in both the Brazos River Valley and in the Greenville experiments, the question is raised as to whether it was sufficiently great to warrant the use of protective or border rows in varietal test plots. It will be seen in Table 1 that the averages for border effect on yield, while differing significantly, were considerably less variable than the averages for the variety effects. The comparison is even more striking in the Greenville experiments.

The increase in land areas, and the increase in experimental error which usually results, are strong points in favor of the use of single-row plots. It was not possible, from these experiments, to compare the magnitude of the error caused by intervarietal competition, which may be expected in experiments with single-row plots, with the increase in experimental error expected when the plot size is increased from one row to three or more rows. In fact, it is practically

impossible, under the usual field conditions, to design an experiment that will give this information.

It is believed that single-row plots will be the most practical kind for general cotton variety test experiments. The possible exceptions are trials in which the entries are known to differ extremely in yield and in plant type, and trials grown on soils of unusually high fertility. It should be kept in mind that intervarietal competition may occur in any variety test on any soil. However, it is apparent, even in tests where the competition is significant, that its effect usually is not great enough to alter significantly the rank of varietal yields.

SUMMARY

Four varieties of cotton, two selected for early maturity and two selected for late maturity, were grown in randomized blocks in the Brazos River Valley. The individual plots were designed in such a way that each variety occurring in the middle row of a plot was bordered on both sides by the same variety and each of the three other varieties. The significant values obtained for border effect were attributed to intervarietal competition.

Two sets of data from Greenville, Texas, in which the sum of the yields of the outside rows of four-row plots was compared with the sum of the yields of the inside rows, were analyzed. Significant intervarietal competition, as measured by the *variety×position* interaction, was found. No explanation is offered for the fact that, as an average of all varieties, the outside rows yielded more than the inside rows.

Considering both the Brazos River Valley and the Greenville experiments, the highest yielding varieties generally were the strongest competitors.

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EFFECT OF SPACING AND SEED SIZE ON YIELD OF POTATOES[1]

B. N. SINGH AND SHANKAR M. WAKANKAR[2]

THE factors of seed size and spacing are of importance in the economy of potato growing; a slight variation in one or both, apart from influencing the yield, affects considerably the initial outlay necessary for planting a required area. While no such work has been reported for India, Bates[3] and Findlay and Sykes[4] have reported that wide spacing reduced total yield and yields of seed and chat potatoes but increased yields and the average size of large ware tubers. Both yield and "net yield" of ware potatoes remained significantly unaffected in their tests. According to these workers, large seed pieces produced the greatest total yield, the greatest "net yield" of ware potatoes, and the most seed. Seed size did not influence the yield of large ware tubers, but the average size of these tubers was greatest from the small seed pieces.

In the absence of local cold storage facilities there is always difficulty in securing the requisite amount of seed potatoes which must be imported from the hills or from certain seed centres. The cost of imported seed is exorbitant during the planting season. The experiment reported here was planned to determine the most suitable spacing and seed size which would be economically suitable and profitable under conditions prevailing at Benares.

ARRANGEMENT OF EXPERIMENT

The Darjeeling red variety of potato was used for the trials. The design of the experiment was a split-plot one, with spacings as the main treatment and the size of seed as the secondary treatment. The main plots were replicated six times.

The spacings chosen for the experiment were 6, 9, and 12 inches from seed piece to seed piece, 6-inch spacing being the local practice. The seed was sorted into three groups for size, as follows: Small, ¾ to 1 inch in diameter, average weight 15 grams; medium, 1 to 1½ inches in diameter, average weight 30 grams; large, 1½ to 2 inches in diameter, average weight 60 grams. The distance between rows was 24 inches.

The "net size" of the main plots was 30×6 feet and of the sub-plots 30×2 feet. It was necessary to resort to such extremely small one-row sub-plots because of the unavailability of the required amount of large seed potatoes.

The experiment was conducted on a rich sandy loam soil on which a previous crop of manured wheat had been grown. A basal dressing of 30 cart loads per acre of yard manure was applied. Planting was done on Nov. 10, 1941, and the plots harvested on March 17, 1942. Before weighing, the produce from each sub-plot was graded by passing it over a 1¼-inch riddle. Potatoes which remained over

[1]Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication April 2, 1943.

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[3]BATES, G. H. A study of the factors influencing size of potato tubers. Jour. Agr. Sci., 25:297–313. 1935.

[4]FINDLAY, D. H., and SYKES, E. T. Influence of size of seed and spacing on the yield of King Edward VII potatoes. Emp. Jour. Exp. Agr., 6:253–261. 1938.

this riddle were termed "large" and those which passed through were termed "small."

Four irrigations were given to the crop. The growth of the vines in all the plots was good. The rows planted with large seed pieces appeared more vigorous, apparently because the large seed produced a greater number of shoots per tuber. The shoots from the three seed sizes were equally tall and strong. In the later stages of growth the crop was slightly affected with late blight, *Phytophthora infestans*, but the damage was insignificant.

The analysis of variance used for calculating the standard errors is shown in Table 1.

TABLE 1.—*Form of analysis of variance (sub-plot basis).*

Variance due to	Degrees of freedom
Whole Plots	
Blocks	5
Spacing	2
Error (1)	10
Total	17
Sub-plots	
Seed size	2
Interaction: Spacing × seed size	4
Error (2)	30
Total	53

RESULTS

The results of the experiment are summarized in Table 2.

Increase in the spacing distance decreased the total yield and the yield of both large and small potatoes, but there was no significant decrease in yield when the spacing distance was increased from 6 to 9 inches. The total yield and the yield of small potatoes was significantly reduced with the wider spacing of 12 inches. There was no significant difference in the yield of large potatoes.

The decrease in the yield of small potatoes with no significant difference in the yield of large potatoes indicated that the size of potatoes, in general, increased as the result of wider spacing. This fact was substantiated by the significant increase in the percentage by weight of large potatoes.

The total yield from large seed was significantly greater than from medium and small seed. The yield from medium seed though higher than from the small seed was not significantly greater. Size of the seed piece did not influence the yield of large potatoes, but the yield of small potatoes was affected considerably. Small seed gave a lower yield of small-sized potatoes when compared with medium-sized seed, and the medium seed gave a lower yield when compared with large seed. Thus, with an increase in the size of seed piece the yield of small potatoes also increased. The percentage by weight of large-sized potatoes decreased significantly with an increase in the size of

seed piece, large seed producing the smallest percentage and small seed the largest percentage of large-sized tubers.

When considering the practical results of an experiment involving a change in seed rate, it is necessary to take into account the quantity of seed used for planting. This is done in the last two columns of Table 2.

TABLE 2.—*Summary of results of experiment, 1941–42.*

Spacing distance, inches	Total yield, maunds per acre*	Yield of large potatoes over 1¼ inches, maunds per acre	Yield of small potatoes up to 1¼ inches, maunds per acre	Percentage of large potatoes in total yield	Seed potatoes required to plant 1 acre, maunds†	Net yield of potatoes after deducting seed, maunds acre
			Small Seed			
6......	165.6	136.1	29.5	82.5	16.6	149.0
9......	156.1	133.7	22.3	85.8	11.1	145.0
12......	121.7	115.1	6.7	94.6	8.3	113.4
			Medium Seed			
6......	167.3	131.2	36.2	78.4	33.2	134.1
9......	160.0	129.5	30.5	81.2	22.2	137.8
12......	134.7	120.5	14.2	89.3	16.6	118.1
			Large Seed			
6......	171.8	127.8	44.0	74.4	66.4	105.4
9......	169.7	129.1	40.6	76.2	44.4	125.4
12......	147.8	126.9	20.9	86.0	33.2	114.6
			Mean Effects of Spacing Distance			
6......	168.2	131.7	36.6	78.4	—	129.5
9......	161.9	130.8	31.1	81.1	—	136.1
12......	134.7	120.8	13.9	90.0	—	115.4
S.E.....	±6.91	±5.39	±2.10	±0.36	—	±6.91
			Mean Effects of Seed Size			
Small...	147.8	128.3	19.5	87.6	—	135.8
Medium	154.0	127.1	27.0	82.9	—	130.0
Large...	163.1	127.9	35.2	78.8	—	115.1
S.E.....	±2.52	±2.44	±1.07	±0.35	—	±2.52
			Spacing × Seed Size			
S.E.....	±4.35	±4.23	±1.85	±0.61	—	±4.35

*1 maund = 82.3 pounds.
†Calculated on basis of 24-inch rows.

From these data it will be seen that after making allowance for the different weights of seed tubers used for each of the treatment, small and medium seed gave significantly larger "net yields" than large seed. The highest net yield, however, was obtained from the small seed. Spacing also influenced the net yield. Increasing the spacing from 6 to 9 inches failed to produce any significant effect, but with

the wider spacing of 12 inches the yield was decidedly reduced. The greatest net yield was obtained with the 9-inch spacing. It will also be noted that with small seed, wide spacing reduced the net yield, but there was no significant difference in yield between 6- and 9-inch spacing. With large seed, however, the yield increased with the 9-inch spacing and decreased again with the 12-inch spacing.

CONCLUSION

These results suggest that under Benares conditions, on rich sandy loam soil, and with the Darjeeling variety, the use of small seed with 9-inch spacing will be found more economical in potato growing than the other treatments studied.

SEED PRODUCTION ON GRASS CULMS DETACHED PRIOR TO POLLINATION[1]

WESLEY KELLER[2]

POPE (11)[3] has shown that barley, *Hordeum vulgare* L., "harvested" prior to flowering produced viable seeds following hand emasculation and pollination, when the detached culms were sustained by distilled water. Harlen and Pope (4) had previously found that barley seeds matured sufficiently to germinate when harvested only 5 days after pollination, and (5) that spikes harvested 3 to 5 days after pollination continued development of the caryopses for at least 8 days if kept moist and in the unthreshed condition. Verret, *et al.* (12) have shown that sugarcane, *Saccharum officinarum* L., would produce viable seeds on canes which were detached prior to pollination and sustained in a 0.05% solution of sulfurous acid. Gruber (3) reported that most of the forage grasses which he investigated would bear viable seeds if harvested 14 days after flowering began. He noted considerable variation between species.

Hermann and Hermann (6) collected seeds of crested wheatgrass, *Agropyron cristatum* (L.) Gaertn., at 3-day intervals beginning 9 days after anther exsertion. None of the seeds harvested 9 days after anther exsertion germinated, either immediately following harvest or during five successive tests conducted at weekly intervals. Seeds harvested 12 days after anther exsertion gave low germination values. Each succeeding period of harvest gave higher germination values than earlier periods, the maximum being reached by ripe seed harvested 36 days after flowering started.

McAlister (10) collected seeds of eight species of grasses at four stages of development, the earliest being 13 to 16 days after full bloom when the seeds were in the pre-milk stage. These pre-milk seeds gave fairly good germination values (70% or more) during the first months of storage. After long periods of storage, however, the decrease in viability was greater in immature than in mature seeds in most instances. He found that hulled seeds of the pre-milk stage, when dry, weighed only 16 to 44% of fully matured seeds.

Although environmental influences encountered by these investigators probably differed, their findings suggest that barley will mature seed in less time, following pollination, than is required by the forage grasses. It was with considerable interest, therefore, that the writer observed, during the winter of 1941–42, that the detached culms of meadow fescue, *Festuca elatior* L., downy chess, *Bromus tectorum* L., and mountain brome, *Bromus carinatus* Hook. and Arn., placed with the cut ends in vials of water prior to flowering produced well-

[1]Contribution of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, in cooperation with the Utah Agricultural Experiment Station and the Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah. Received for publication March 19, 1943.

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[3]Figures in parenthesis refer to "Literature Cited", p. 623.

developed seeds under bags. A sufficient number of seeds was produced to suggest that in making crosses the female parent may be transported to the pollen source in contrast to the customary procedure of conveying the pollen to the intact female. This is an extension of technic which may frequently be useful in practice. The present study was undertaken to determine the feasibility of the method under field conditions.

MATERIALS AND METHODS

The grass species used were those available which were near the flowering stage on June 30, 1942, when the experiment was initiated. The species are listed in Table 1. Culms were severed 2 or 3 inches above the crown and inserted into pint fruit jars through nail holes in the lids. The purpose of the lids was to reduce water loss from the jars by evaporation. As a further means of reducing evaporation, the jars were partly submerged in the soil on the shady side of a row of grass. This row of grass provided a source of pollen for those species which naturally cross pollinated by wind. None of the inflorescences were emasculated, therefore self pollen probably functioned for those species which are naturally selfed. The culms, standing in water, with no leaves removed, were held upright by securing them to a vertical wire stake with a small identification tag. No further attention was given this material until 28 days later when the ripened inflorescences were transferred to paper bags. At this time most of the jars contained only a small quantity of brackish water; others were dry. A few inflorescences showed evidence of some shattering or mechanical injury. Some normal inflorescences from intact culms were also harvested to permit comparison of seed size and germination. After drying thoroughly, the material was hand threshed and cleaned, the seeds counted and weighed. Seeds from detached culms of some species threshed free of the glumes in which case the glumes were removed from similiar seeds produced on intact culms in order to obtain valid weight comparisons. Germination values were determined by planting all of the seeds produced, up to 100, in a silty clay loam soil on a heated greenhouse bench. The seeds were covered lightly (1/8 to 1/4 inch) and the soil kept moist.

RESULTS

SEED PRODUCTION

Nine of the 11 species included in the test produced seeds, as indicated in Table 1. With few exceptions the seed yields were considered to be good. Shattering reduced the yield from *Agropyron ciliare* and *A. cristatum*, also from one lot each of *A. semicostatum* and *Festuca elatior*. The best seed yields were obtained from *F. elatior* which gave almost 100 seeds per panicle, and from some of the lots of *A. trachycaulum*, *A. semicostatum*, and *Bromus inermis*, each of which approached or exceeded 50 seeds per spike or panicle. Only one panicle of *Bromus carinatus* was included in the study. It gave a low yield of seed. Culms of *A. ciliare* (C), *A. trachycaulum* (M), and *Hordeum jubatum* (W) which were detached before the inflorescences had completely emerged from the boot all gave good seed yields. *Phalaris arundinacea* and *Phleum pratense* failed to produce any seeds. The pollen source of these two species was very limited and flowering had almost been completed when this study started. Seeds

TABLE 1.—*Number of seeds and weight and germination of seeds produced on detached and intact culms.**

Species and stage of development of inflorescences when detached from the parent plant	Number of culms, or spikelets	Total seeds	Relative weight	Per cent germination	Relative germination
Agropyron ciliare (Trin.) Franch.					
Normal (B)	—	—	100	80	100
(A) Ready to flower	2†	4	83	100	125
(C) Half out of boot	5	22	55	27	34
A. cristatum (L.) Gaertn., Normal (E)	—	—	100	45	100
(D) Ready to flower	1	7	67	29	64
A. semicostatum (Steud.) Nees.,					
Normal (FK)	—	—	100	76	100
(G) Flowering had started	3	11	48	64	84
(H) Same; large seeds	22	47	67	60	79
(I) Same; medium size seeds	12	33	18	12	16
(J) Same; smallest seeds	16	24	9	0	0
A. trachycaulum (Link) Malte,					
Normal (L)	—	—	100	97	100
(M) Half out of boot	77	206	71	100	103
A-785; Normal (N)	—	—	100	86	100
(O) Flowering had started	58	90	71	86	100
(P) Ready to flower	45	34	53	79	92
Bromus carinatus Hook. and Arn.,					
Normal (Q)	—	—	100	71	100
(R) Half out of boot	1	7	71	57	80
B. inermis Leyss., Normal (S)	—	—	100	94	100
(T) Ready to flower	2	124	30	33	35
(U) Ready to flower	1	52	45	22	23
Hordeum jubatum L. Normal (V)	—	—	100	96	100
(W) Half out of boot	3	91	40	88	92
Festuca elatior L. Normal (Z)	—	—	100	56	100
(X) Ready to flower	2	190	67	53	95
(Y) Just out of boot	2	190	59	57	102
Phalaris tuberosa L. ready to flower	2	28	—	96	—
P. arundinacea L. ready to flower	2	0	—	—	—
Phleum pratense L. ready to flower	2	0	—	—	—

*Capital letters in parentheses identify each lot in Fig. 1. Normal refers to mature seeds harvested from intact culms.

†In this column numbers 1 to 3 designate culms, whereas higher numbers refer to spikelets. There was evidence of shattering or other mechanical injury in lots designated by the following capital letters: A, C, D, G and X.

might have resulted with a more abundant pollen supply. Therefore, the data presented are not considered sufficient proof that these species are incapable of seed production by the method in question.

The number of seeds produced per culm is not considered a reliable indicator of the potential seed-producing capacity of the individual

species, since the number of inflorescences used was small. The principal point of interest is that culms detached from the parent plant and placed in water under the conditions of this experiment were capable of maturing seeds. Representative seeds from each lot are illustrated in Fig. 1.

RELATIVE SEED WEIGHT

All the seeds produced on detached culms were lighter in weight than those which matured naturally. Most species had some detached culms which gave seeds one half or more the weight of normal seeds. Several exceptions occurred, however. Three spikes of *Agropyron semicostatum* yielded seeds of readily distinguished sizes, the weights being 67, 16, and 9% of normal, respectively. *Bromus inermis* seeds from detached culms were only 30 and 45% of normal and those of *Hordeum jubatum* 40% of normal. Seeds of *A. semicostatum*, *Bromus carinatus*, and *B. inermis* from detached culms threshed free of the glumes. In order to determine comparative weights the glumes were removed from normal seeds of these species. In the remaining species the glumes adhered to the caryopses, and were not removed to determine relative weights. These values therefore are relative weights of caryopses plus glumes. Since the glumes on detached culms appear normally developed (Fig. 1), the values given in Table 1 are probably higher than they would be if determined from caryopses alone.

GERMINATION

Seeds matured on intact culms required less time to germinate than those from detached culms. Examination of the seedbed one week after planting revealed good germination from most of the seeds matured normally, but little germination from those matured on detached culms. After 12 days, however, the chief difference was in size of seedlings and after 18 days size difference between species were much greater than those between treatments. Percentage germination was based on apparently normal seedlings which emerged through 1/8 to 1/4 inch of moist soil. The germination test was started 3 1/2 months after the seeds were harvested, and final counts reported in Table 1 were taken 18 days later.

In general, germination of seeds from detached culms was only slightly below that of seeds from intact culms. *Bromus inermis*, *Agropyron ciliare*, and the smaller seeds of *A. semicostatum* were exceptions. Normally matured seeds of *A. cristatum* and *Festuca elatior* gave low germination values, for which no explanation is apparent. A low germination value was obtained for *A. ciliare* seeds from a culm detached when the spike was half out of the boot. This can be partly explained by examination of typical seeds in Fig. 1 (C), compared with normal seeds (B). The dark color of the latter, in contrast to the sterile appearance of the former, is a direct reflection of the extent to which the caryopses had developed in each. It is apparent from this that most of the relative weight reported for "C" in Table 1 is due to an apparently normal development of the glumes on detached culms.

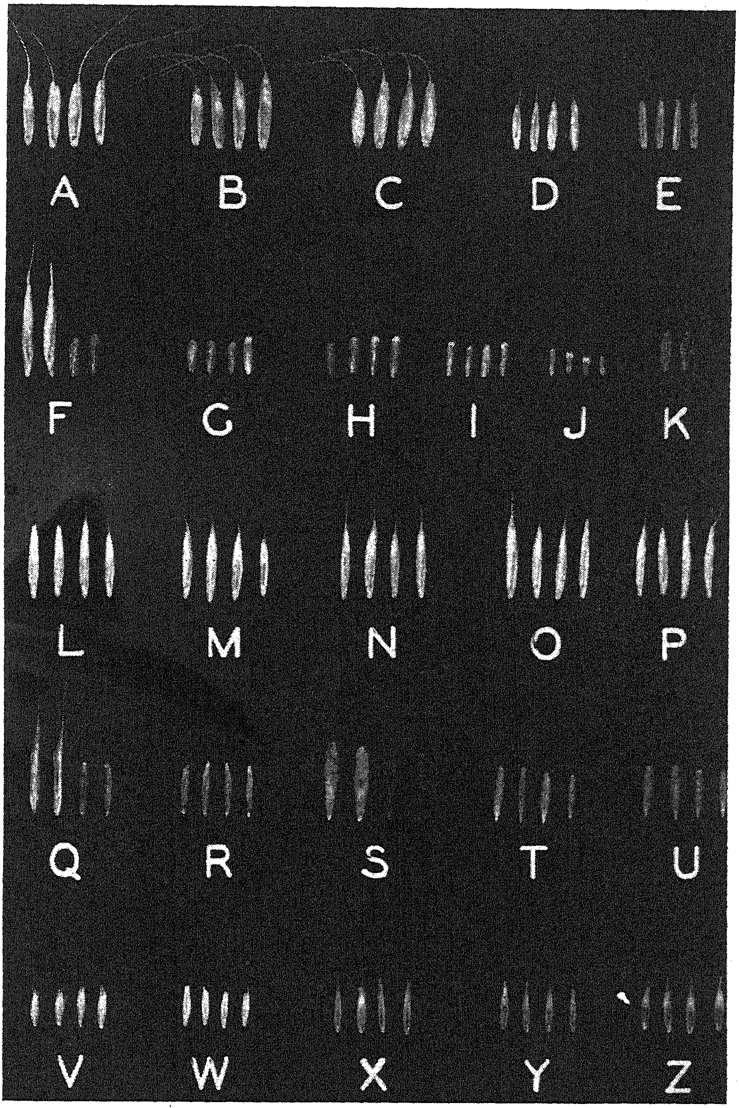

FIG. 1.—Grass seeds produced on detached and intact culms. A–C, *Agropyron ciliare;* A, detached when ready to flower; B, normal; C, detached when half out of boot. D–E, *Agropyron cristatum;* D, detached when ready to flower; E, normal. F–K, *Agropyron semicostatum;* F, normal; G–J, detached when flowering had started; G, plant A. H to J, plant B; H, largest seeds; I, medium size seeds; J, smallest seeds; K, normal. L–P, *Agropyron trachycaulum;* L, normal; M, detached when half out of boot; N–P, strain A-785; N, normal; O, detached when flowering had started; P, detached when ready to flower. Q–R, *Bromus carinatus;* Q, normal; R, detached when half out of boot. S–U, *Bromus inermis*, S; normal; T & U, detached when ready to flower. V–W, *Hordeum jubatum;* V, normal; W, detached when half out of boot. X–Z, *Festuca elatior;* X, detached when ready to flower; Y, detached when just out of boot; Z, normal.

DISCUSSION

Preliminary trials have demonstrated that several species of forage grasses will mature viable seeds on culms which have been detached prior to pollination. This method of seed production does not alter the necessity for emasculation if controlled hybrids are desired. The maximum amount of seed which can be produced on detached culms will require further investigation. The environmental forces encountered will probably always constitute an important element in the production of seeds by detached culms under field conditions. Flowering and early seed development of the species studied normally occur at Logan, Utah, during the period of June 10 to July 15. Temperatures for 23 years show an average daily gain of approximately one-third degree F, increasing from 78° F on June 10 to 90° F by July 15. If high temperatures are injurious to seed setting, it appears that the earlier the pollinating can be done the better. Maximum temperatures for 1942 showed wide fluctuations during June, owing chiefly to storms. This was followed by higher than normal temperatures from July 2 to 14. July 4 to 7, inclusive, maximum temperatures ranged between 93° and 96° F. It was during this period that the plants under study were either flowering or in early post-pollination stages. The average daily minimum temperature increased from approximately 50° F on June 10 to 60° F by July 15, while the minimum daily temperature for 1942 fluctuated in a manner closely resembling that of the 1942 daily maximum. It is clear that the plants studied in 1942 withstood considerably higher than average temperatures. The experiment was conducted at the end of the flowering period when temperatures were excessively high. It is probable, therefore, that as far as temperatures are concerned, seed production on detached culms would be possible in most seasons. No records are available regarding wind movement, but the area generally is characterized by Alter (1) as having light to moderate winds, a high percentage of sunshiny days, and low relative humidity, all favoring rapid evaporation.

According to Jenkins (8), corn tassels survive and shed viable pollen longer if the water in which they are placed contains sodium bisulfite in the proportion of 1 to 2,000 (0.05%). Brandes and Sartoris (2) reviewed the various cane breeding technics, including that of Verret, *et al.* (12) referred to in the introduction. They report that sugar cane arrows detached prior to flowering will mature viable seeds if the canes are sustained in a solution of sulfurous acid and phosphoric acid, each 1 to 1,000. Canes placed in this solution actually grew and remained fresh a month, but in water alone they would survive only a day or two. This is a remarkable demonstration of the role of chemicals in plant breeding. On the other hand, Hitchcock and Zimmerman (7) tested 51 chemicals, including sulfurous acid, in an attempt to prolong the life of cut flowers without significant results. Laurie (9) noted that copper had a bactericidal action, but its use failed to add materially to the life of cut flowers. Seed production in grasses by post-harvest pollination might be materially improved by the use of chemicals. The conflicting results obtained on

other species of plants indicate that this may require experimental determination for each species of grass.

Pope (11) cut about 1 inch from the lower end of his barley culms several times during the course of his investigation. It is possible that this treatment might be beneficial to grass. Maintaining fresh water in the jars may prove beneficial. For practical use the detached culms should not remain in the field for a month, as in the present study. In periods of extremely hot or windy weather, some advantage may be gained by removing the detached culms to a protected area as soon as pollination has been completed.

SUMMARY

Under field conditions at Logan, Utah, the following species of forage grasses will mature viable seeds on culms detached prior to pollination and placed with cut ends in tap water in proximity to appropriate pollen sources; *Agropyron ciliare*, *A. cristatum*, *A. trachycaulum*, *Bromus carinatus*, *B. inermis*, *Hordeum jubatum*, *Festuca elatior*, and *Phalaris tuberosa*. Viable seeds were also produced on culms of *A. semicostatum* which had already begun to flower when they were detached. *Phalaris arundinacea* and *Phleum pratense* failed to produce any seeds by post-harvest pollination, but from the limited scope of the study little significance should be attached to negative results.

Most lots of seeds from detached culms weighed from 40 to 83% of those matured on intact culms. Seeds from detached culms of *A. ciliare*, *A. trachycaulum*, *H. jubatum*, and *F. elatior* germinated approximately as well as those from the control lots of the same species. Germination was fairly high for other species with the exception of *B. inermis* which gave values of 25 and 35%.

Grass seed production on culms detached prior to pollination constitutes an extension of technic which may be useful in practical breeding operations.

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GROWTH AND DECAY OF THE TRANSIENT (NONCAMBIAL) ROOTS OF ALFALFA[1]

FRED REUEL JONES[2]

IN the course of a study of the mycorrhizal fungus in the roots of legumes the writer in 1924 (4)[3] recorded an extensive dying of the ends of alfalfa rootlets in midsummer at a time when they were making little growth. Subsequent observations have confirmed the opinion that this occurs regularly to a greater or less extent in the vicinity of Madison, Wis., even with the most favorable climatic conditions and cutting treatment. During the recent dry summers a well-irrigated nursery has been used in which root dying has been found to take place even more severely than in some of the drier fields. Among a large number of clones of plants of diverse growth character and three or four years of age in this irrigated nursery, it appeared that those which were more dormant in the summer lost more rootlets than those which were less dormant, and all lost rootlets earlier than alfalfa in some of the fields on nearby farms. Finally, among inbred lines grown in the irrigated nursery and selected for wilt resistance and winter hardiness, a few declined in vigor after two or three years of growth with no apparent cause other than a poorly developed root system. From this it appeared that there might be important differences among plants in their responses to root-destroying agencies.

With this background, in 1941 a systematic examination of the roots of alfalfa was begun to trace the development of this decay. Since no study of seasonal elongation of rootlets in old alfalfa plants has been published, it was necessary to supply this in rough outline also, and this soon involved, in turn, examination of the morphology of the roots involved. The results obtained in this examination of rootlet decay in relation to the growth and morphology of the roots affected is presented in the following pages. The determination of the organisms causing decay remains to be completed.

REVIEW OF LITERATURE

No explicit description of seasonal growth and decay of alfalfa rootlets has been found in the extensive literature of root growth in that plant. In the extensive data on root growth recorded in studies of root storage in relation to management practices and to winterkilling, only the large storage roots have been considered, in comparison with which the rootlets furnish very little weight if collected. It may be inferred from the following descriptions that root storage and root elongation in old plants may not be strictly contemporaneous developments and may even be fundamentally incompatible.

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, in cooperation with the Wisconsin Agricultural Experiment Station, Madison, Wis. Received for publication March 26, 1943.

[2]Senior Pathologist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering.

[3]Figures in parenthesis refer to "Literature Cited", p. 634.

The rootlets of old plants appear to have been examined most critically by those who were chiefly interested in them as the origin of nodules, and, in fact, the closest approach to a partial statement of the spring growth and summer decay of rootlets in alfalfa and some other legumes appears to have been made by those interested primarily in the often observed decay of nodules in summer. Fred, *et al.* (2, page 190) in a discussion of the normal life of the nodule state, "In other words, the formation of new nodules or the development of new lobes upon existing nodules closely parallels the development of new rootlets." But even in the subsequent discussion of premature destruction of nodules they do not note a situation often found in alfalfa in which the nodules decay along with the rootlets to which they are attached. Thus, the parallel between nodule formation and decay and rootlet formation and decay is not completed.

Wilson (10, Figs. 2 and 3), illustrating the disappearance of nodules in consequence of experimental cutting treatment in white clover, apparently illustrates the disappearance of the rootlets to which the nodules are attached along with the nodules, though he does not mention this association.

The branching habit of the mature alfalfa root system has been correctly illustrated by Weaver (9, Figs. 101–102), branches from the taproot reaching only to the fourth in numbered order. While Eames and MacDaniels have stated (1, page 133) that, "... in some woody species a considerable proportion of fibrous rootlets contain only primary growth", no examination of these branches in alfalfa appears to have been made to determine if any of them consistently remain primary in structure, a matter of first importance in the pathology of these roots. Several studies of the morphology of alfalfa roots reviewed and extended by Simonds (6) and summarized by Hayward (3) are concerned chiefly with the seedling, and with the large roots that are of interest as storage organs. The development and maturity of the peripheral rootlets in plants several years of age does not appear to have been examined.

PERMANENT AND TRANSIENT ROOTS OF ALFALFA

In the examination of the root systems of alfalfa it was soon found desirable to distinguish at any time, if possible by macroscopic examination, between smaller rootlets which had begun secondary thickening and those which were still primary in structure. The importance of this distinction came from the observed fact that the decay described in detail later was entirely of primary root structure. The result of this decay in its extreme development in old plants was to strip the root system at the end of the summer of nearly all of the rootlets which had no well-developed secondary growth leaving comparatively few roots, but leaving the remaining rootlets little harmed and capable of developing new branches in the fall and spring. The more complete removal of the noncambial roots from old plants made such plants more convenient for the observation of the year-round behavior of roots; therefore, the following observations have been made on plants 2 years old or older unless otherwise stated.

Among the smaller roots it is obviously impossible to distinguish those which are primary in structure from those which have some secondary thickening on the basis of size. Rootlets which are primary in structure differ among themselves greatly in diameter (Fig. 1, A and B) and sometimes have a vascular cylinder which occupies but a

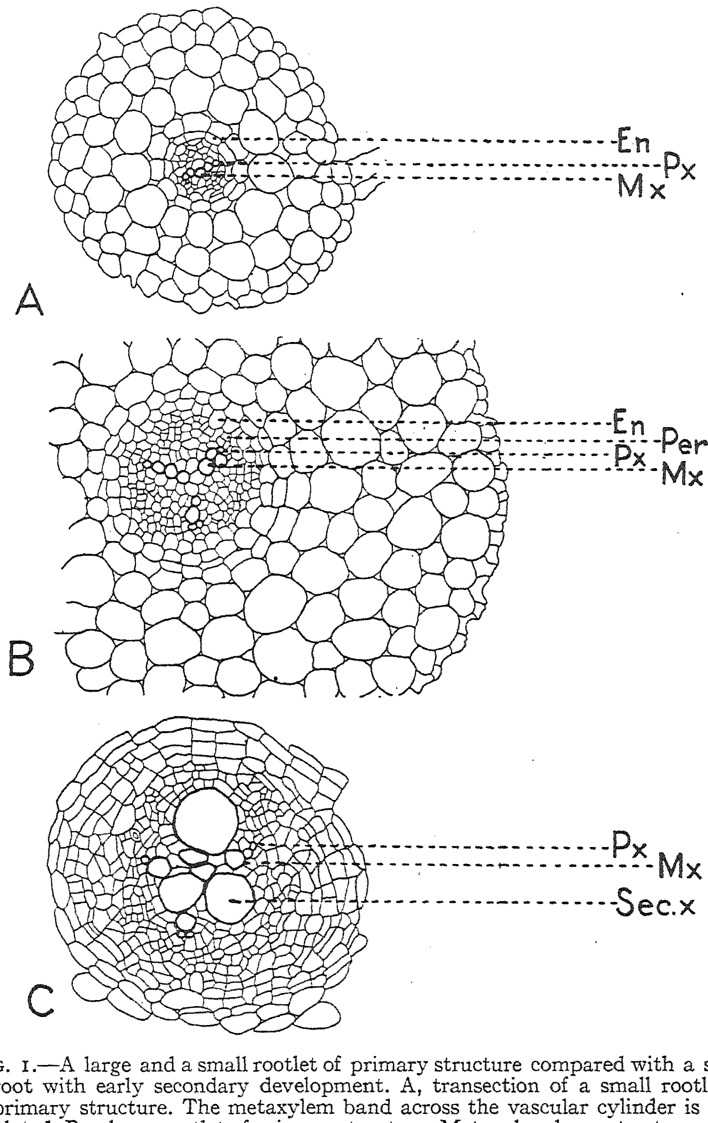

FIG. 1.—A large and a small rootlet of primary structure compared with a small root with early secondary development. A, transection of a small rootlet of primary structure. The metaxylem band across the vascular cylinder is completed. B, a large rootlet of primary structure. Metaxylem has not yet appeared at the center of the root. C, transection of a rootlet beginning secondary thickening rather weakly in summer. The two largest vessels appear to be secondary in origin, possibly the third large vessel also. The phellem is in an early stage of development. en, endodermis; mx, metaxylem; px, protoxylem; per, pericycle; sec. x., secondary xylem. ×170.

twentieth of the cross sectional area. Thus rootlets which have shed their primary cortex with its four to six layers of large cells between the endodermis and the piliferous layer and have begun secondary

thickening are smaller in diameter than before cambial activity began. Thus, to determine internal structure, the sectioning of many rootlets was necessary. The usual method of imbedding rootlets in paraffin for sectioning requires so much time and results in so much shrinkage that the rootlets were usually sectioned immediately, imbedded in bundles in 5% agar. The agar blocks were sectioned readily as soon as cool, and even better after they had been placed in 70% alcohol for a day or more. If root hairs were not abundant, the root sections floated out of the agar and could be collected for staining and mounting. The remaining agar blocks were imbedded in paraffin and sectioned later in the usual way, if necessary.

Secondary thickening in rootlets is initiated by the cambium and, subsequently a phellogen, derived from the pericycle, begins to cut off cork also. In the smallest rootlets the cambial strands are at first inconspicuous, the number of cells produced from them are few, and thus the earliest vessels formed from the cambium are not always easily distinguished from the last vessels formed in the centripetal maturity of the metaxylem (Fig. 1, C). This is especially true in rootlets from a clay subsoil where vessels produced from both sources are few and of great diameter with consequent disarrangement of the surrounding cells. It is often true in rootlets produced in cool weather when metaxylem appears to mature over a long period. Thus, a precise determination of the inception of cambial activity is often very difficult. Fortunately, the subsequent development of the phellogen which is necessary for the preservation of the root can be seen easily, and in doubtful cases this is the most useful evidence of secondary growth. Among the old plants under study it was found that very few of the young rootlets produced in a season have an active cambium. Thereupon search was made for the condition that determined why some young rootlets terminated axial enlargement upon the maturation of the primary tissues, while others continued to grow as a result of cambial activity. A search in the primary structure of rootlets for indication of their future potentialities has thus far been in vain. The rootlets that become permanent are usually among the largest, and the largest are usually triarch rather than diarch, though some of the very smallest are triarch. No strict relationship between the size of a rootlet or the number of its primary vascular bundles and its future development became apparent. The clue to the probable development of a rootlet was finally found in its position in the root system.

The branching habit of the alfalfa root system is well illustrated by Weaver (9, Figs. 101 and 102). The taproot is shown with branches differing greatly in length and size. The largest of these branch, and these in turn, until the fourth branches numbered in order from the taproot are reached. No branches beyond this fourth order shown by Weaver have been found in the plants examined. When branching occurs to the fourth order, the first two branches are found with much secondary thickening from cambiums which appear to have developed early in the growth of the root. These branches with secondary thickening together with the taproot are conveniently called the permanent root system of the plant, or the cambial roots.

From this permanent root system arise many branches, usually short, but sometimes quite long, which may in turn have a few short branches. These branches originate in the first instance in the usual manner opposite protoxylem points in the primary roots, but they may die and be succeeded again and again by others from the same place of emergence after the secondary tissues have been added to the permanent roots. These rootlets and their branches rarely develop cambiums, at least no complete phellogen, and thus they appear unable to survive indefinitely. There appears to be no established term distinguishing such shortlived roots from the permanent roots. Warning (8) has designated as transient roots in parsnip rootlets that may have an even shorter duration than those in alfalfa, and may in part have a dissimilar origin; but provisionally this term may serve. Thus, these shortlived rootlets are designated transient roots, or the noncambial root system. The positional relation between the permanent and the transient roots is shown in Fig. 2.

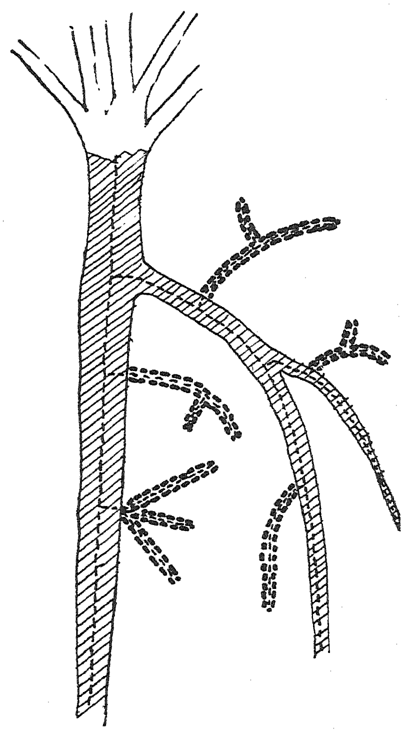

FIG. 2.—Diagramatic representation of a longi-section of the mature root system of alfalfa showing branching habit and distinguishing permanent and transient roots. Cross-hatching represents permanent structures, crown, and permanent roots (////). Broken lines represent transient structures, vascular cylinder of roots and primary cortex of roots.

Additions to the permanent root system are made frequently in old plants from rootlets which grow more rapidly than their neighbors, and which develop cambiums. Sometimes several rootlets near each other go through the early stages of the formation of permanent roots, developing cambiums that decline in activity before many vessels have been matured. Among these a strict classification of cambial and noncambial roots cannot be made. However, the instances in which the classification of rootlets cannot be made clearly have not occurred often enough to impair the utility of the distinction between the permanent and the transient roots. The same classification can be made almost equally well in sweet clover, and probably in other biennial plants. In addition to the roots shown by Weaver in the figures cited above, plants may develop an adventitious root system from the crown when the stems have become well overgrown with rootlike tissues, and when soil moisture is maintained about the

crown. The adventitious roots develop like branches from the taproot, or, if this is lost, like new taproots.

SEASONAL GROWTH OF TRANSIENT ROOTS

The plants used most frequently in the tracing of root growth were from the nursery to which reference has been made. Roots were also obtained from fields on farms for comparison at critical seasons. The estimate of root elongation from time to time was made by successive records of the length of rootlets found on similar locations in the root system, and by the color of the roots and the distance of the mycorrhizal fungus from root ends at some seasons. The records of mitotic figures used by Stuckey (7) to indicate growth in her study of the growth of grass roots did not appear to be practicable in this instance. The opinions reached should be regarded only as a rough survey from which only the outstanding features of growth habit may be outlined.

In the spring very few transient roots are found emerging and little elongation takes place prior to top growth. The period of most vigorous root growth begins following the inception of vigorous top growth early in May, and continues until, or almost until, the plants begin to flower. The precise time at which this grand period of root growth begins to decline is often difficult to determine because in most years the soil becomes dry early in June, and this condition may itself retard root growth. In 1942 frequent showers in June kept the surface so moist that roots often lacked root hairs as in water cultures, and even under this condition it appeared that the rate of root growth began to decline early in June. By the Middle of June root growth was greatly lessened, and in plants left uncut till the first of July there was little evidence of the emergence of new roots, and those which were not killed as described later did not appear to be growing. From this time on through the summer very few new rootlets appeared, and surviving transient roots grew slowly if at all.

A second, lesser period of growth begins about the middle of September when moisture is abundant and extends into October, declining with the colder weather or the killing of tops by frost. In this period growth is found chiefly in the adventitious roots or in roots near the surface of the soil, but not in roots 2 feet or more deep as in spring growth. No growth has been detected in winter. In the late autumn of 1941 some rows of alfalfa were heavily mulched before the ground froze that roots might be kept unfrozen for observation during the winter. Even in the spring when etiolated shoots formed, no root elongation was detected. It may be noted that, while root growth is described above as occurring in two periods, it is possible and perhaps equally useful to regard these periods as essentially one which is interrupted by winter.

Root growth in the summer has been far more inactive than anticipated. In the dry season of 1941 it was suspected that the drought was restricting root growth and recovery after the first cutting. Therefore on July 3 a portion of some rows that had been cut 10 days earlier was freely irrigated and a part of the irrigated tract was

heavily mulched to reduce soil temperature. The irrigation did not greatly stimulate top growth, and root growth was not much increased even where the mulch was used.

Since transient roots grow rapidly when the first crop is developing fast in the spring, it was anticipated that a corresponding growth of roots would be found accompanying the second crop. This anticipated correlation between root and top growth has not been found. Apparently, in this locality, the second crop is produced upon the surviving part of the transient root system produced largely in the growth of the first crop with very little addition developed along with the second crop.

Parenthetically it is noted that on this meagre summer growth of rootlets few nodules are found, though in a previous study (5) a high soil temperature was found to favor nodule formation. A partial explanation of the failure of nodule formation may be found in the position of the mycorrhizal fungus in those rootlets at this time. Wipf and Cooper (12) have described the development of nodules from disomatic cells located near the endodermis, which is the region in which the mycorrhizal fungus advances filling cells with "arbuscles". In summer this fungus advances close to many root ends and in so doing may occupy the disomatic cells before the infection thread of rhizobium reaches them, or, at least, early enough to prevent them from becoming meristematic after they are infected. When this occurs, the invading bacteria would apparently become pathological agents contributing to the destruction of the outer cells of the root as described by Fred, *et al.* (2, page 823).

It is interesting to note further that in the transient roots the metaxylem usually produces some vessels of a size and character corresponding to the dominant type produced at the same time by the cambium. In summer when large vessels are being laid down by the cambium in the cambial roots, the last metaxylem vessels produced in the maturing primary root are of great diameter also, even though it appears that the latter large vessels do not join directly with the large ones in the main root, but rather communicate with them through a group of small vessels at the base of the rootlet. Metaxylem vessels produced in the autumn are small as in the main root, and it is not certain that differentiation proceeds to completion in many of them until spring. Thus, the metaxylem of the transient roots has similarities in morphology with the contemporaneous secondary xylem in the permanent roots.

In contrast with their behavior in old plants, the roots of seedlings or of cuttings set in the ground in the spring do not show in their first year the extreme periodicity in growth described above. Here root growth is most active in spring and again in fall, but there is moderate growth during the entire summer, especially if the tops are not cut back. While it is perhaps premature to suggest reasons for the differences in behavior in root growth between seedlings and old plants, it may be noted that Stuckey (7) suggests that in grasses the production of new roots may be inhibited by developing flower primordia. Wilton and Roberts (11) also state from a study of several species that the flowering stem is characterized by a less active

cambium than nonflowering stems. While these authors refer to a stem cambium only, it is possible that root procambiums develop similarly.

SEASONAL DECAY OF TRANSIENT ROOTS

The following account of the decay of transient roots in alfalfa is compiled from observations made in selected locations where it appeared that the injury observed came initially from microorganisms in the soil rather than from drought or other unfavorable soil conditions. Judgment may easily have been in error in making the selection, and therefore conclusions lack the support which should come from a more precise knowledge of the etiology of the injury. The important fact for the present is that these rootlets do die in great numbers, and at different times in different locations.

The earliest indication of root deterioration in spring is usually the greenish yellow discoloration of the cortex following the invasion by the mycorrhizal fungus. This appears in the latter part of May. Early in June a browning of the cortex of rootlets begins to appear, some of which may be due to the mycorrhizal fungus, but some of which may be found independently of this fungus in the underlying cells. Species of Fusarium have been isolated from such rootlets, but their pathogenicity has not been determined. The yellowing may begin in small areas and spread until the entire rootlet is discolored nearly to the region of elongation. By the middle of June this browning is abundant, and the ends of some of the rootlets are decayed. No branching of the rootlet back of the decayed region has been observed to carry on the extension of the rootlet. Rootlets with discolored cortex and decayed ends die back to their origin in a permanent root. New roots may arise at the base of dead roots, and these may die in turn until at the end of the summer clusters of three or even more dead rootlets are found. Rootlets do appear to respond by branching to physical injury. Sometimes when the ends of rootlets are destroyed by insect feeding, a branch emerges back of the elongating region, and the rootlet resumes growth without much delay.

The extent of this decay in rootlets differs greatly in different locations. In the clonal nursery it may be proceeding so rapidly in mid-June that the transient root system is no longer increasing in extent, and by the end of June the transient roots formed in spring may have comparatively few living root ends. From mid-July through August the transient roots furnish little absorbing surface for the support of foliage, and in fact the second crop is very small in this nursery. The decay has been found undiminished in severity in the subsoil 3 feet from the surface. In clones of highly dormant Ladak alfalfa destruction appears more complete than in clones of more actively growing Grimm. In fact, the transient roots through which presumably water absorption largely takes place are nearly absent for so long in the more dormant clones that it seems possible that this condition may lead to their deterioration and death.

From observations in farm fields, it is evident that root decay does not everywhere begin as early or proceed as rapidly as in the irrigated nursery. The field with the best preserved roots found in

1942 had produced an excellent second crop. The fact that the mycorrhizal fungus was found close to the ends of the roots in the summer in this field indicated that they were growing very slowly, but the root ends were living. On the basis of a few local observations it appears that a vigorous second crop may be evidence of the preservation of a large part of the root system that developed with the first crop. It is hoped that a more extended examination of this relation can be made later.

DISCUSSION OF RESULTS

The distinction drawn in this paper between the noncambial or transient rootlets and the cambial or permanent roots makes it easier to emphasize in studies of root diseases that the two kinds of roots not only have fundamentally different diseases, but that they have fundamentally different abilities to react to disease. Moreover the transient roots react differently to their fungus invaders as they pass through different stages of their growth cycle until as growth becomes very slow, it may be impracticable to distinguish precisely between disease and the disintegration which must follow inactivity. That plants may survive for a long period in the year with very little transient root system has become apparent. But the growth of the plant while such rootlets are few is clearly small in quantity and different in character from that while such rootlets are abundant. For economical crop production, it certainly appears necessary that most of the transient rootlets developed in spring should be retained until late in the summer. In an exploration of the extent to which this is possible, the degree to which the decay of transient rootlets is due to conditions that may be properly called disease—and disease that can be controlled—must be determined. It is possible that low productivity in second and third cuttings and reduced yields in stands several years of age may be found associated with the death of transient roots early in the summer.

SUMMARY

The dying of alfalfa rootlets in summer at Madison, Wis., which has been mentioned briefly by the writer previously, has been reexamined as a phase of the obvious, but apparently undescribed, root succession in this plant.

Rootlets die following a browning and shrinking of the primary cortex in which the mycorrhizal fungus may or may not be present, and following a soft decay of the ends of rootlets. The agents causing decay are not determined.

Two kinds of roots are distinguished in alfalfa on the basis of morphology, duration, and function. They are described as the permanent or the cambial roots and the transient or noncambial roots. The permanent roots, serving for transport and storage, consist almost entirely of secondary growth from a cambium and a phellogen, and are limited to the taproot, a few of its branches, and a few of the branches from the first branches. The transient roots arise in the usual manner from the permanent roots, but they develop little or

no cambium and no phellem. When these rootlets die they may be replaced by new transient rootlets emerging near their bases.

The rate of transient root growth and regeneration differs greatly during the growing season, and this periodicity of growth is much more marked after the first year. The period of most vigorous root growth begins in May after the stems have begun rapid elongation, and reaches its maximum about the first of June. Growth declines by the middle of June, and by the first of July reaches a minimum that persists through the summer. In the latter part of September roots near the surface of the soil become active in growth and continue thus, but with lessened vigor as cold increases in October. No appreciable growth has been found in winter even when the soil is protected from freezing.

Root deterioration begins in late May or early June, and increases rapidly from the middle to the end of June. Where decay is severe, the development of rootlets in July and August appears to be largely inhibited by the decay of root ends almost as soon as they emerge. The severity of the decay differs in different fields, and in plants with different habits of growth. It seems possible that the early decay of transient roots limits to some extent the growth of the second crop.

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NOTES

FAILURE OF VETCH TO EXCRETE NITROGEN FROM THE NODULES WHEN GROWN IN ASSOCIATION WITH NITROGEN-DEFICIENT CITRUS SEEDLINGS[1]

IN connection with studies of nitrogen gains and losses in California soils, an experiment was set up in pot culture to determine whether nitrogen-starved citrus seedlings would show any benefit when grown in association with vetch. The thought was to determine whether nitrogen excretion from root nodules might occur under the climatic conditions prevailing in this region. Though the original findings by Virtanen, *et al.*[2] have been substantiated by Wilson,[3] the latter has concluded that nitrogen excretion by legume nodules probably depends on climatic conditions which favor nitrogen fixation rate, on the one hand, but limit photosynthetic rate on the other. Under such conditions fixed nitrogen is not utilized in growth as rapidly as it is formed and thence may accumulate in and be excreted by the nodule.

Sweet orange seedlings were transplanted into a series of 18 2-gallon pots filled with a uniformly mixed loam soil of low nitrogen content, on August 23, 1937. The plants were allowed to grow in the greenhouse until February 9, 1938, by which time all plants had ceased growing and were very yellow owing to extreme nitrogen deficiency. Sweet orange seedlings in such a state will become green and resume growth within 10 days if given nitrogen but without nitrogen will remain essentially dormant for months.

On the aforementioned date, inoculated purple vetch was planted in 8 of the 18 plots. The vetch germinated well and the cultures were kept in the greenhouse until April 15, 1938, by which time the vetch had made substantial growth. There was no sign of greening or growth of the citrus seedlings in the vetch pots, however.

In order to alter the climatic conditions, all of the pots were taken out of doors on April 15. At the end of 1½ months of further growth out of doors there was no change in the appearance of the citrus seedlings in the vetch pots as compared with the controls, hence the experiment was discontinued.

Pictures were taken of the tops and roots of representative pots and the dry weights (Table 1) of the tops of all plant material in each pot obtained. Pictures showing the appearance of the tops of the seedlings with and without vetch, the nodulation of the vetch roots, and the intertwining of the vetch and citrus roots are presented in Fig. 1.

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[1]Paper No. 486, University of California Citrus Experiment Station, Riverside, Calif.

[2]VIRTANEN, ARTTURI ILMARI, HANSEN, SYNNÖVE VON, and LAINE, TAUNO. Investigations on the root nodule bacteria of leguminous plants. XIX. Influence of various factors on the excretion of nitrogenous compounds from the nodules. Jour. Agr. Sci., 27:332–348. 1937.

[3]WILSON, PERRY W. The biochemistry of symbiotic nitrogen fixation. Univ. Wisconsin Press, Madison, Wis., 142–162. 1940.

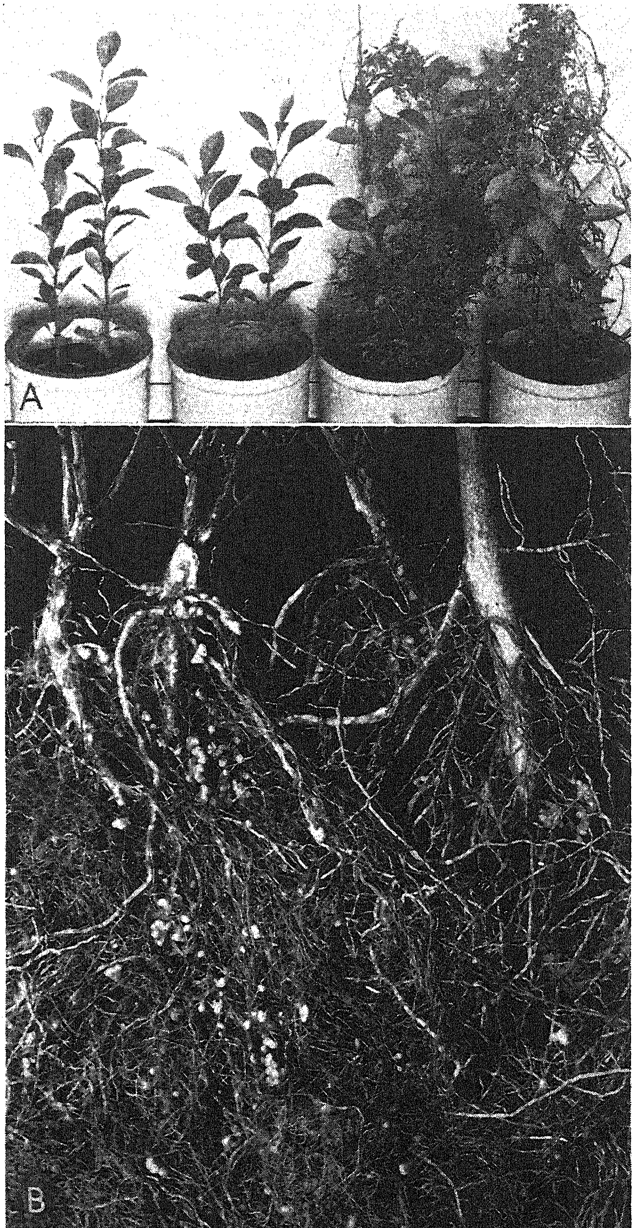

FIG. 1.—A, tops of nitrogen-starved citrus seedlings growing alone and in association with vetch; B, roots of citrus seedling (extreme right), and of three vetch plants. Note nodulation of vetch and intertwining of roots of the citrus and vetch.

TABLE 1.—*Dry weight of citrus seedlings grown with and without vetch.*

Pot No.	Oven-dry weight of tops, grams			
	Citrus per pot	Average	Vetch per pot	Average
1	17.7	—	10.7	—
2	9.0	—	13.0	—
3	8.3	—	20.4	—
4	12.4	10.6	15.8	19.5
5	8.1	—	21.6	—
6	7.2	—	32.2	—
7	10.1	—	16.6	—
8	11.9	—	25.7	—
9	14.3	—	—	—
10	17.3	—	—	—
11	9.6	—	—	—
12	13.7	—	—	—
13	13.8	13.1	—	—
14	9.3	—	—	—
15	19.9	—	—	—
16	13.6	—	—	—
17	10.0	—	—	—
18	9.8	—	—	—

It is apparent from both the dry weight data and the failure of citrus leaves in the vetch pots to show green that no benefit accrued to the citrus seedlings from the associated growth with vetch; hence it can be asserted that no significant excretion of root nodule nitrogen occurred.—H. D. CHAPMAN, *University of California Citrus Experiment Station, Riverside, California.*

MULTIPLYING PEANUT HYBRIDS BY VEGETATIVE PROPAGATION

HYBRIDIZATION of peanuts, *Arachis hypogea*, is a tedious task. The buds must be emasculated at night for pollination the following morning. Approximately 10 minutes is required for each complete pollination. The average fruit set from hand-pollinated flowers is seldom more than 60%, with an average of 1.5 seeds per fruit. Virginia type peanut plants spaced 12 inches apart in 3-foot rows will produce from 50 to 100 seed. Thus, 10 to 20 hand-pollinated F_1 seed are required to produce the 1,024 F_2 seed theoretically necessary to obtain all genetic combinations if five factors are segregating. Hull[1] and Higgins, *et al.*,[2] have reported enormous amounts of segregation occurring in peanut hybrids which is supported by the senior author's observations on hybrids of small-podded and large-podded types. Hull reports evidence of duplicate genes and polyploidy. It appears that most of the desired characteristics in peanuts are

[1]HULL, FRED H. Inheritance of rest period of seeds and certain other characters in the peanut. Fla. Agr. Exp. Sta. Bul. 314. 1937.

[2]HIGGINS, B. B., HOLLEY, K. T., PICKETT, T. A., and WHEELER, C. D. I. Peanut breeding and characteristics of some new strains. Ga. Agr. Exp. Sta. Bul. 213:3–11. 1941.

governed by several to many genes making a large segregating (F_2) population necessary for success in peanut breeding work.

In January 1942, 40 vegetative cuttings were made from greenhouse-grown plants. After treating with a hormone solution and placing in moist sand, all cuttings formed good roots in 10 days. These cuttings were grown to maturity in the greenhouse. Only fair plant development was obtained since the cuttings were allowed to become pot-bound in 3-inch pots before transplanting to the ground bed.

A small field test was conducted in 1942 to compare the yielding properties of vegetative cuttings as compared with plants from seed. Three standard peanut types were chosen, *viz.*, large bunch (N. C. Sel. 32 of Va. Bunch), medium runner (a farmer's stock known locally as Knight's or Martin County Runner), and small bunch (Spanish 2B, a large Spanish selection). Cuttings were made from greenhouse-grown plants. Lateral branch cuttings and main stem cuttings were kept separate throughout the test. At the time of transplanting into the field (May 22) seed of each variety were planted as checks. A randomized split-pot design of six replications of 10 plant plots was used. The three sources of plants (main stem, lateral branch, and seed) made up the sub-plots, while the three strains comprised the whole plots.

The results (Table 1) show no significant difference between the two sources of cuttings. The yield of plants from seed was significantly less than that for plants from main stems but not so for plants from lateral branches. Time of planting has a marked influence on peanut yields so if the seed had been planted 2 weeks earlier it is reasonable to expect plants from this source might have produced as much as those from main stem cuttings. When the sources of plants are considered by individual strains, some interesting differences are observed. The late-maturing Virginia bunch shows plants from seed produced significantly less than plants from either of the other two sources. On the other hand, the early-maturing Spanish strain produced approximately equally from the three plant sources. N. C. 32 and Martin County runner show significant differences in yield for plants from lateral branches and those from main stem cuttings.

TABLE 1.—*Yield of peanut strains from vegetative cuttings and from seed, yield of unshelled nuts adjusted for missing plants given as pounds per acre.*

Strain	Lateral branch	Main stem	Seed	Av. for strain*
N. C. Sel. 32	1,237.8	1,514.4	890.0	1,193.9
Martin Co. Runner	1,002.5	1,281.6	1,173.9	1,132.4
Spanish 2B	1,127.6	1,026.7	1,028.1	1,101.0
Av. for source of plants*	1,122.3	1,274.6	1,030.0	

*Adjusted for missing plants on basis of whole plot error variance.

There is an inherent factor present in the Virginia bunch and runner strains which presumably may account for the differential yield of the two sources of cuttings. The main stem in these two strains never

bears flowers, i.e., only lateral branches bear flowers. On the other hand, Spanish plants bear flowers on both the main stem and lateral branches. The difference in flowering habit was noticeable very early in the plants from cuttings. Plants from main stem cuttings of N. C. 32 and Martin County runner did not flower on the main stem but developed lateral flower-bearing branches. Plants from lateral branch cuttings of these two strains started or continued to flower on the original branch now serving as a main stem. The most striking difference occurred in the runner strain. The lateral branch cuttings, even though forced to serve as a main stem, again became prostrate and developed as a lateral branch on a normal plant. This geotropic response caused the complete development of the lateral cutting plant to be to one side of the root attachment. The main stem developed in all respects as a normal plant putting out new runner laterals and fruiting only on these branches. All plants attained approximately normal amount of growth and branching. The development of typical plants of the Spanish strains are shown in Fig. 1 as the plants were dug in September.

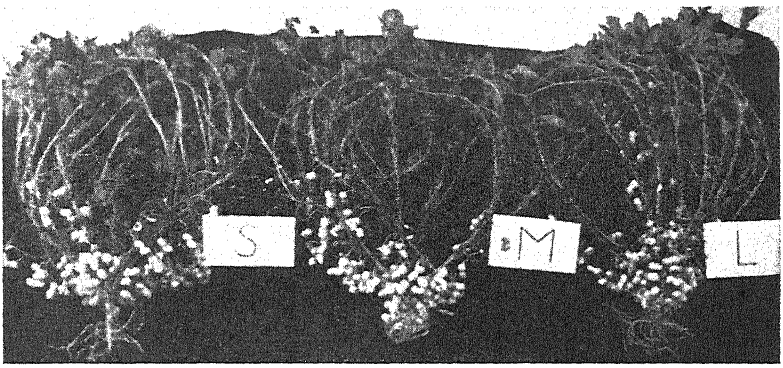

FIG. 1.—Typical Spanish plants after digging in September. S, from seed; M, from main stem; L from lateral branch cutting.

The cutting technic makes it possible to test F_1 peanut hybrids in replicated yield trials if desired. Immer[3] has recently pointed out the advantages of early testing of hybrid populations in self-pollinated crops. It is possible to gain this information for peanut hybrids with a relatively small amount of actual crossing. Three cuttings can be made from a vigorous 6-week-old plant. From plants thus obtained a second set of cuttings could be made in two or three months time. Thus, in one winter season, one F_1 plant could be multiplied 20 to 50 or more plants by spring planting time. In addition to permitting yield trials on the F_1 plants the amount of F_2 seed produced would be vastly increased. Special tests such as chemical analyses which destroy the seed might be made without unduly reducing the size of the F_2 population.—PAUL H. HARVEY and E. F. SCHULTZ, JR., *North Carolina Agricultural Experiment Station, Raleigh, N. C.*

[3]IMMER, F. R. Relation between yielding ability and homozygosis in barley crosses. Jour. Amer. Soc. Agron., 33:200–206. 1941.

BOOK REVIEWS

FUNDAMENTALS OF SOIL SCIENCE

By C. E. Millar and L. M. Turk. New York: John Wiley & Sons, Inc. London: Chapman & Hall, Ltd. XI + 462 pages, illus. 1943. $3.75.

ACCORDING to the authors, this volume, prepared as a college textbook and as a reference book for anyone interested in soils and their management, has a fourfold object, "To give the reader the opportunity to become familiar with soils as natural units or entities and with their inherent characteristics, to develop in the student an understanding of the significance of fundamental soil properties, to set forth basic relationships between soils and plants, and to give the reader an understanding of the principles involved in the use of proved soil-management practices."

A critical examination convinces the reviewer that the authors have ably accomplished all four of these objectives. Technical enough for the average student in soils, its simplicity and directness of statement will also appeal to the non-student who wants to know something of the why and wherefore of many of our soil-management practices.

The scope of the book is suggested by its 19 chapter headings which include soil development, classification, physical and chemical properties, reaction and its regulation, moisture, biology, organic matter and various manures, plant nutrition and nutrients, fertilizers and their use, and productivity ratings. The last five chapters are given over to more specialized subjects, such as agriculture in arid regions, irrigation, fruit and lawn soils and the soil resources of the United States. Lists of student questions are given under many of the sub-headings. After the text a valuable nine-page glossary of terms is given, followed by what appears to be an excellent index.

The book can be unhesitatingly recommended to anyone interested in gaining a comprehensive knowledge of the science of soils. (R. C. C.)

WORLD TRADE IN AGRICULTURAL PRODUCTS

By Henry C. Taylor and Anne Dewees Taylor. New York: Macmillan Company. XVIII + 286 pages, illus. 1943. $3.50.

THE authors, Director of the Farm Foundation of Chicago and independent research student in the history of agricultural economics, respectively, bring to bear on this study of agricultural products in their economic aspects, a broad background of training, travel, and research in this field. The book presents an authoritative world picture of "the underlying motives and far-reaching effects of national trade policies, of imperial preferences, of international trade agreements, and of all sorts of production and trade restrictions, also relationships between standards of living and widespread controls that force agriculture, industry, and commerce into uneconomic channels". According to the authors the study was prepared as a contribution to the factual background needed for an appraisal of the problems that face the builders of a world social struc-

ture designed to provide the conditions essential to the progress of civilization.

The work was given incentive and extension through the senior author's membership on the Permanent Committee of the International Institute of Agriculture in Rome. This Institute published in Rome in 1940 the very extensive "World Trade in Agricultural Products: Its Growth; Its Crisis; and the New Trade Policies". Since very few copies of this study, or of a 96-page summary made later, ever reached the United States, the present volume has been prepared largely from this more extensive work.

Each of the major agricultural products is discussed separately, and includes a world map showing the net trade of the principal importing and exporting countries, charts of volume and gold value of world exports, and statistical tables. A separate chapter discusses government policies.

This work and the collaboration of the U. S. Dept. of Agriculture in various ways has, without doubt given us the most authoritative book available on this vitally important subject. It can be recommended without reservation. (R. C. C.)

EXPLORING TOMORROW'S AGRICULTURE: COOPERATIVE GROUP FARMING—A PRACTICAL PROGRAM OF RURAL REHABILITATION

By Joseph W. Eaton, with foreword by M. L. Wilson. New York and London: Harper & Brothers, XVI + 255 pages, illus. 1943. $2.75.

IN THIS volume the author, who is Director of Research of the Rural Settlement Institute, presents what he considers a possible solution to a very important rural problem, one which will undoubtedly become more acute after the war. This problem in his own words is, "How can farmers in general, and low-income farmers in particular, get an adequate and secure income to live by, a stimulating and important type of work to live for, a pleasant and well-integrated community to live in, a happy family and friends to live with and enough leisure to just live?"

The author thinks the solution lies in the cooperative group farm and the book is an intimate study of this movement. It first deals with the theory of cooperative group farming, including such topics as the ten criteria which are used as a standard of rural rehabilitation, the tasks and obstacles involved, resettlement, large-scale and family farming, and an outline of a possible program.

The second section gives some analysis of the cooperative corporation farms of the Farm Security Administration, as to their layouts, objectives and philosophy, establishment, membership and program, management, measure of success, and future possibilities. The last section deals with other types of cooperative group farms, both in this country and abroad.

This book is a thought-provoking one which will undoubtedly help to shape our future thinking in an important sociological field. Anyone in the least interested in the position of the farmer in the post-war world should read it. (R. C. C.)

AGRONOMIC AFFAIRS

LITERATURE ON THE MINOR ELEMENTS

THE Chilean Nitrate Educational Bureau, Inc., announces publication of the fourth supplement to the third edition of the "Bibliography of References to the Literature on the Minor Elements and Their Relation to Plant and Animal Nutrition."

The first edition of this bibliography was published in August 1935, the second in November 1936, and the third, the last complete edition, in February, 1939. Subsequently, the first supplement was published in April 1940, the second in April 1941, and the third in May 1942.

The fourth supplement contains about 94 pages and 690 abstracts, which include 110 crops and 30 elements. There are 887 authors listed. Complete indices are provided, including an element index, a botanical index, and an author index which includes the names of all authors listed in the various abstracts. Also, at the suggestion of Dr. W. O. Robinson of the U. S. Dept. of Agriculture, a number of elements which previously have been classified individually, now are grouped together under the heading "Rare Earths".

For further information about this new supplement, write to the Chilean Nitrate Educational Bureau, 120 Broadway, New York City.

AGRICULTURAL SPECIALISTS AND AGRICULTURAL AIDS SOUGHT FOR FEDERAL SERVICE

PERSONS who have had agricultural experience or education are being sought for Federal Civilian War Service. Agricultural Specialists in extension, research, program planning, and conservation are paid from $2,600 to $6,500 a year (plus overtime pay); however, appointments to positions paying over $4,600 will be few. Applicants must have had experience or education, or a combination of the two, involving some scientific or technical aspect of agricultural production or distribution, or some other scientific or professional phase of agriculture such as rural planning, farm finance, and rural education. Experience may have been gained in such agriculture activities as extension, research, college teaching, program planning, conservation, and vocational agriculture teaching. Some positions require farming experience.

Agricultural Aids are needed to assist in semitechnical laboratory or field work. Two to four years of technical experience in agriculture or the equivalent in agricultural study in college is required. The positions pay from $1,970 to $2,433.

Applications should be filed with the Civil Service Commission, Washington, D. C. There are no age limits and no written examinations. Further information and application forms may be obtained at first- and second-class post offices, or from the Commission's Regional or Washington offices.

NEWS ITEMS

According to Science, Dr. George D. Scarseth has been appointed Head of the Department of Agronomy, Purdue University, Lafayette, Ind., effective July 1. Doctor Scarseth, who has been serving as Professor of Soils and as Soil Chemist at the Purdue University Experiment Station since 1937, succeeds Professor A. T. Wiancko who is retiring on June 30 after serving for 40 years. Professor Wiancko is a charter member of the American Society of Agronomy.

—A—

Eric W. Stark of the Texas State Forest Service has been appointed Associate Professor of Forestry in the School of Agriculture and Associate in Forestry and Conservation in the Experiment Station, Purdue University, Lafayette, Ind. He will carry on research and teaching in wood properties and wood utilization.

—A—

The Annual meeting of the Canadian Seed Growers' Association was held at St. Dunstan's College, Charlottetown, P. E. I., June 22 and 23.

—A—

Professor Dale A. Hinkle of the Department of Agronomy, New Mexico College of Agriculture and Mechanic Arts, State College, N. M., has been granted leave of absence for the duration of the war to accept a commission as Lieutenant (J. G.) in the Navy.

—A—

Doctor W. B. Ellett, Head of the Department of Agricultural Chemistry at the Virginia Agricultural Experiment Station, Blacksburg, Va., died on May 12 after an illness of almost four months.

—A—

E. F. Henry, Assistant Agronomist assigned to soil survey work at the Virginia Agricultural Experiment Station, has resigned to accept a position in the Navy as a Lieutenant (J. G.). Mr. Henry's place has been filled by J. H. Petro, a graduate of Ohio State University who was formerly employed by the Soil Conservation Service in their survey program.

—A—

Doctor A. L. Grizzard, Associate Agronomist in charge of the pasture investigations work in the Agronomy Department, Virginia Agricultural Experiment Station, resigned on May 1 to accept a position with the office of Inter-American Affairs and is stationed in El Salvador.

—A—

J. D. Guthrie, in charge of the experimental farm of the Virginia Agricultural Experiment Station and also in charge of the plant breeding work in the state, resigned on June 10 to accept a position with the office of Inter-American Affairs. He is stationed in Bolivia. The position vacated by Mr. Guthrie has been filled by the appoint-

ment of Dr. Malcolm H. McVicker. Doctor McVicker received his undergraduate training at the University of Illinois and received his Ph.D. from Ohio State University in 1939. Previous to reporting to Blacksburg on his new assignment he was employed by the Farm Security Administration.

—A—

DOCTOR FIRMAN E. BEAR, Chairman of the sub-committee on Nitrogen Utilization on Haylands and Pastures of the national joint committee on Nitrogen Utilization, has announced the personnel of the sub-committee as follows: R. B. Becker, Florida Agricultural Experiment Station, Gainesville, Fla. (Florida, Georgia, Alabama); C. B. Bender, New Jersey Agricultural Experiment Station, New Brunswick, N. J. (New Jersey, Delaware, Maryland); B. A. Brown, Connecticut Agricultural Experiment Station, Storrs, Conn. (New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut); R. W. Cummings, North Carolina Agricultural Experiment Station, Raleigh, N. C. (North Carolina, South Carolina, Virginia); D. R. Dodd, Ohio Agricultural Experiment Station, Wooster, Ohio (Ohio, Indiana, Michigan, Wisconsin, West Virginia); D. S. Fink, Cornell University, Ithaca, N. Y. (New York, Pennsylvania, Maine); H. J. Harper, Oklahoma Agricultural Experiment Station, Stillwater, Okla. (Oklahoma, Kansas, Nebraska, Texas); M. A. Hein, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. (Washington, Oregon, California); H. H. Lush, National Fertilizer Association, 616 Investment Building, Washington, D. C. (Louisiana, Mississippi, Tennessee, Kentucky); and H. H. Tucker, Educational and Research Bureau, 50 West Broad St., Columbus, Ohio (Illinois, Iowa, Missouri, Arkansas, North Dakota, South Dakota). Each member will undertake to study the work that is being done in the states following his name. Doctor D. S. Fink will summarize the work in this field before Section IV of the Soil Science Society in Cincinnati in November. It is also expected that the sub-committee will convene during the Cincinnati meetings to consider the 1944 program.

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EFFICIENCY STUDIES OF TYPES OF DESIGN WITH SMALL GRAIN YIELD TRIALS[1]

J. H. TORRIE, H. L. SHANDS, AND B. D. LEITH[2]

PROBLEMS concerned with varietal testing are of prime interest to agronomists in relation to the determination of the adaptation and yield of named varieties and new hybrids for the purpose of making recommendations to farmers. Experiment stations commonly have available a large number of selections for yield tests. Many of these can be eliminated by deficiencies that can be detected by observation, yet many remain that require yield trials to determine their productive capacities. It is important that as much information be secured as possible from the use of small plots. During the past few years considerable interest has been focused on the lattice designs developed by Yates (18)[3] as a means of increasing precision. Many experiment stations test varieties simultaneously in rod rows and in larger field plots. The question then arises as to whether the relative response of the varieties is the same for both methods of testing. Some investigators harvest quadrats in place of the entire plot. The principal questions are, first, how many quadrats per plot are necessary to give the desired precision, and second, how do the responses of the varieties as measured by quadrats compare with those determined on the entire plot basis. In this paper data obtained during the past 6 years by the Wisconsin Agricultural Experiment Station at Madison are used as a study of the points mentioned above.

MATERIALS AND METHODS

The data used in this study consist of the grain yields from the wheat, oats, and barley rod-row and 1/60-acre plot experiments conducted by the Department of Agronomy at the University Hill Farms, Madison, Wis., during the period 1937 to

[1]Contribution from the Department of Agronomy, Wisconsin Agricultural Experiment Station, Madison, Wis. Published with the approval of the Director. Paper No. 185. Received for publication March 26, 1943.

[2]Assistant Professor, Associate Professor, and Professor of Agronomy, respectively. The authors wish to thank Dr. Churchill Eisenhart, Statistician, Wisconsin Agricultural Experiment Station, for his counsel in selecting the methods of statistical analysis used and for his assistance in the preparation of the manuscript; and Dr. R. G. Shands for making available to the authors the data for the spring wheat rod row tests for the years 1937 to 1942, inclusive.

[3]Figures in parenthesis refer to "Literature Cited", p. 660.

1942. Data obtained from the oat rod-row nurseries at the Hancock and Marshfield branch experiment stations during the period 1938 to 1941 are also included. The 1938–39 winter wheat trial is not included in the comparison of the lattice and randomized complete block designs because of severe differential winter injury in one replication.

The technic used for the rod-row nurseries will be described briefly. All tests were replicated four times. The shape of an individual replicate block was made as nearly square as possible. This was accomplished by arranging the varieties within a replication in two tiers with the exceptions of the 1938 oat test and one of the 1942 oat tests with single rows for which three and one tiers were used, respectively. Each of the rod-row plots consisted of three rows, 18 feet long and 1 foot apart, with the exception of the last oat test listed in Table 1 for which single-row plots were used. At harvest the middle 16 feet of the center row was taken for yield. Since 1938 the lattice design has been used for the oats, barley, and winter wheat nurseries.

The more promising varieties were tested in 1/60-acre plots, with the exception of the spring grains during 1937 and 1938 when 1/80-acre plots were used. The 1/60- and 1/80-acre plots are referred to as field plots in this paper. During the 5-year period of 1937 to 1941, four quadrats were harvested from each plot. The quadrats were taken at random with the restriction that each quarter of the field plot be sampled. The quadrats were 4×4 feet square. The field plots and rod-row nurseries were usually located on different fields.

COMPARISON OF LATTICE AND RANDOMIZED COMPLETE BLOCK DESIGNS

Lattice designs, formerly called pseudo-factorial or quasi-factorial, were first described by Yates (18). Later Yates (19) reported a more accurate method of analysis by which inter-block information is recovered. The purposes of the lattice designs are to provide a more accurate method than randomized complete blocks when a large number of varieties are to be tested and to retain as far as possible equal accuracy of comparison between every pair of varieties in the test.

A review of the literature on lattice designs shows that they are more precise in most comparisons than randomized complete blocks. Yates (18) and Goulden (8), using data from uniformity trials without recovery of inter-block information, found the lattice designs more precise than randomized complete blocks. Yates in two studies reported gains of 26% and 57%, while Goulden concluded from a study of 26 sets of data that the incomplete block designs were 20% to 25% more precise on the average than randomized complete blocks. Later studies by Cox, *et al*, (6), Cochran (5), and Zuber (20), using Iowa corn data, in which inter-block information is recovered, indicated substantial gains for the lattice designs. Cochran (4) reported on the results of six wheat experiments conducted by L. R. Waldron at Fargo, N. D., with the number of varieties ranging from 49 to 169. Two showed no gain, one a gain of 2% while the other three showed gains of 39%, 45%, and 156%. Cochran (5) from a study of 20 triple lattice experiments conducted with corn in Iowa calculated that three replicates of the triple lattice design were somewhat more

accurate on the average than five replicates of the type of randomized block design used, but that somewhat smaller increases could be expected with a more compact replication. Zuber (20), using data from a corn yield uniformity trial in Iowa, reported an average increase in precision of 36% over randomized complete blocks for the following incomplete block designs, lattice, triple lattice, balanced lattice, and lattice square.

The results from 22 lattice designs used on the present investigations are shown in Table 1. The data are arranged according to crop, year, and location of the tests. The data include the variance of the

TABLE 1.—*Relative efficiency of the lattice design, with and without recovery of inter-block information, compared with the randomized complete block design, based on rod-row data from several Wisconsin experiment stations.*

Crop and location	Year	Design	Variance of the difference between two varietal means, bu.			Mean yield per acre, bu.	Relative precision factor	
			R.C.B.*	R.	I.		R.	I.
Oats, Madison	1938	9×10	21.47	19.86	23.81	44.0	108	90
	1939	7×7	33.32	31.11	35.16	59.3	107	95
	1940	8×8	51.19	50.38	58.45	73.6	102	88
	1941	8×8	46.92	37.37	39.38	60.6	126	119
	1942	7×7	79.78	79.75	101.23	77.7	100	79
	1942	7×7	60.83	55.10	61.37	79.9	109	92
Mean........							109	94
Oats, Hancock	1938	4×5	3.52	3.24	3.88	17.8	109	91
	1939	4×5	5.04	5.04	6.92	20.3	100	73
	1940	4×5	8.28	7.75	9.37	38.2	107	88
	1941	4×5	17.04	14.93	17.45	24.3	114	98
Oats, Marshfield	1938	4×5	10.08	10.08	13.21	17.6	100	76
	1939	4×5	19.09	17.61	22.22	41.5	108	86
	1940	4×5	27.02	25.90	32.07	40.1	104	84
	1941	4×5	36.45	35.68	45.25	69.6	102	81
Mean........							106	85
Barley, Madison	1938	8×8	19.61	19.17	22.57	42.1	101	87
	1939	6×7	9.60	8.90	9.58	42.0	108	100
	1940	6×7	20.21	11.66	12.18	45.3	173	166
	1941	7×7	17.52	17.51	22.13	25.3	100	79
	1942	8×8	27.61	27.33	31.99	40.9	101	86
Mean........							118	104
Winter wheat, Madison	1940	7×7	18.18	15.18	17.90	38.3	112	102
	1941	7×7	17.52	17.51	22.13	25.3	100	79
	1942	7×7	12.29	12.29	15.39	39.7	100	80
Mean........							104	87
Mean of all tests.....							109	92

*R.C.B. = Randomized complete blocks; R = Inter-block information recovered; I = Inter-block information ignored.

difference between two varietal means for the randomized complete block and the lattice, with and without recovery of inter-block information, as well as the relative precision of the lattice in respect to the randomized complete block. The variance of the difference between two varietal means ($s^2_{\bar{d}}$) was calculated by the method described by Cox, *et al.* (6). For the randomized complete block $s^2_{\bar{d}}$ is $\frac{2s^2}{r}$. For the lattice design without recovery of inter-block information it is $\left[\frac{(2s^2)}{r}\right] \cdot \left[\frac{(k+3)}{(k+1)}\right]$, and for the lattice design with recovery of inter-block information it is $\left[\frac{2s^2}{r(k+1)}\right] \cdot \left[\frac{4w}{w+w'}+(k-1)\right]$. In the preceding formulae s^2 is the error mean square, r the number of replications, k the number of varieties in an incomplete block, $w=\frac{1}{s^2}$ and $w'=\frac{3}{4B-s^2}$, where s^2 and B are, respectively, the error and block mean squares. In the above formulae for $s^2_{\bar{d}}$ for the lattice design the expressions given are the mean variances of differences between two varietal means. The actual values differ somewhat from these depending upon whether the two varieties to be compared are in the same or different incomplete blocks.

The variance of a difference between two varietal means ($s^2_{\bar{d}}$) has a definite relation to the minimum difference required for significance between two means. The minimum difference required for significance between varietal means at the .05 or .01 levels is t at .05 or .01 for error degrees of freedom times $\sqrt{s^2_{\bar{d}}}$. The relative precision factor for the lattice was obtained by dividing the $s^2_{\bar{d}}$ for randomized complete blocks by that for the lattice design. If a precision factor of 125% is obtained, it means that four replicates in a lattice design are as efficient as five in randomized complete block trials.

The average gain in precision of the 22 lattice designs with recovery of inter-block information is only 9%, while without recovery of inter-block information there is an average loss of 8% in precision. Only one test, that for barley in 1940, showed a large increase in precision, namely, 73%. Eighteen of the 22 experiments gave an increase of less than 10%, while 11 showed less than 5% gain. There was no pronounced difference in gain in relative precision of the lattice designs for the different crops. The small increases in precision obtained indicate that the variation between incomplete blocks within a replication is essentially the same as the variation between the individual plots within an incomplete block. In other words, there are few or no real differences in productivity between the incomplete blocks within a replication. The conclusion should not be drawn from the above data that lattice designs under all conditions could be expected to give only a slight gain in precision on the average over randomized complete blocks. Where there is a sizeable difference between incomplete blocks, the lattice designs will give considerable increase in precision.

The data presented in this paper, when considered in relation to the literature reviewed, indicate that lattice designs under some conditions will give large gains in precision whereas in other instances the gains may be small. This indicates that each experiment station will probably have to determine locally what gains may be expected from the use of lattice designs as compared to randomized complete blocks, rather than to depend entirely upon the results obtained at some other station. The question may be raised as to the advisability of using a lattice design in place of the randomized complete block where experience over a period of years shows that the gain in precision is small, as has been the case at Madison. As pointed out by Cochran (4), to a person who is familiar with lattice designs, the extra work involved in the statistical analysis of the data is a small fraction of the total. Another worthwhile point is that occasionally a really large gain in precision may be obtained as evidenced by the 73% gain for the 1940 barley trial at Madison. This increase in precision in terms of the minimum difference required for significance between two varietal means amounts to 2.14 bushels per acre. The minimum differences required for significance with the randomized complete block and the lattice design with recovery of inter-block information are, respectively, 8.89 and 6.75 bushels per acre. Moreover, with the recovery of inter-block information the lattice design cannot be less precise than the randomized complete block. This would indicate that the experimenter who is willing to take a little more trouble in statistical analysis has nothing to lose and everything to gain. The use of lattice designs in situations where missing values are of frequent occurrence may be undesirable owing to the greater complexity of the analysis when values are missing.

COMPARISONS OF ROD ROWS, FIELD PLOTS, AND QUADRAT SAMPLES OF FIELD PLOTS

In varietal testing of cereal crops the question is often raised as to whether the varieties react differentially for grain yields under differend methods of testing. The results of several investigations indicate that a good agreement between methods exists when quadrats harvested from drill-sown plots are compared with the entire plot for yield of grain. The number and type of quadrats recommended by the different investigators varies considerably. Kiesselbach (11) recommended 20 systematically distributed quadrats each 32 inches square. Arny and Garber (1) in fertilizer trials with spring wheat found that nine rod rows harvested from 1/10-acre plots gave results practically as accurate as harvesting the entire plot. Arny and Steinmetz (2) from a study of 1/10-acre cereal plots at several locations in Minnesota recommended 4 to 5 square-yard quadrats for plots where the stand is uniform and up to 10 where the stand is not uniform. Clapham (3) and Kalamkar (10) found that it was necessary to harvest 30- and 36-meter lengths, respectively, from 1/40-acre plots to obtain a sampling error of approximately 5%. Michels and Schwendiman (14) recommended that for cereal crops 12 to 18 square yards be harvested from 1/40-acre plots to provide yields comparable to those of entire plots.

The literature comparing the results obtained from small nursery plots such as rod rows and larger drilled plots show, in general, excellent agreement. Kiesselbach (12) reports good agreement between winter wheat strains sown in rod rows and in larger drilled plots. Hayes, *et al.* (9) from a comparison of the yield of 16 highly selected varieties of spring wheat grown in 1/40-acre plots and in rod rows using different rates of seeding found the best agreement when rod rods were seeded at a heavy rate. Klages (13) compared the yields of small grains in rod rows and drilled plots over a 3- to 4-year period by means of correlation and comparison of rank. In general, his results showed good agreement using the two types of plots. Smith and Myers (16) found good agreement between the yields of 12 timothy varieties grown in rod rows and 1/50-acre plots. Frankel (7) from a 5-year study of three to eight wheat varieties found a close agreement between the yield of samples from large drilled plots and square yard plots. Smith (15) compared yields of nine wheat varieties in 1/100-acre plots harvested by sampling with those obtained from square yard plots. He reported a close agreement using the two methods.

In order to determine if the varieties reacted similarly for the different methods of testing yielding ability, the variety-type of plot interaction was tested by comparing its mean square with that of error by the F test. A significant F value would indicate that certain of the varieties responded differently under the two methods of test. In order to determine which varieties reacted differently, the following formula was used in the comparison of the quadrats and 1/60-acre plots with the rod rows: $d = \bar{D} \pm t\sqrt{\frac{s^2}{r} \cdot \frac{2(N-1)}{N}}$, where d = difference required for significance between means of the two methods for a variety, $\bar{D}$ = average difference between the two methods, s^2 = error mean square, r = number of replications, N = number of varieties, and t = .01 level of "t" for the degrees of freedom of the error mean square.

Since the difference required for significance is dependent upon both the difference within a variety for the two methods and the average difference for all varieties between methods, $\frac{N-1}{N}$ was used in the above formula. The proof is as follows:

$$d_1 - \bar{D} = d_1 - \frac{d_1 + d_2 + \text{------} + d_N}{N}$$

$$= \frac{(N-1)d_1 - \sum_{i=2}^{N} di}{N},$$

where d_1 is the difference between the two methods of testing for any one of the varieties. Since for independent variables d_1, d_2 ---- d_N, with common variance σ^2_d, the variance of $a_1 d_1 + a_2 d_2 + \text{--} + a_N d_N$, where the a's are constants, is $(a_1^2 + a_2^2 + \text{---} + a_N^2)\,\sigma^2_d$, it is evident that

$$\sigma^2_{d1} - \overline{D} = \frac{1}{N^2}\left[(N-1)^2 + (N-1)\right]\sigma^2_d$$
$$= \frac{N-1}{N^2}\left[(N-1)+1\right]\sigma^2_d$$
$$= \frac{(N-1)}{N}\sigma^2_d$$

In the comparison of the quadrats and field plots a different formula was used than when the rod rows were compared with the quadrats and field plots. The reason is that since the quadrats are parts of the field plots, there is a correlation between the yields of the two methods which must be considered. The formula used to determine how much difference is necessary for significance considering the quadrat and field plot yields of a variety is,

$$d = \overline{D} \pm t\sqrt{\frac{\overline{s^{2\prime}}}{r} \cdot \frac{N-1}{N}},$$

where $s^{2\prime} = \dfrac{\left[\begin{array}{l}\text{error sums of squares for plots} + \text{error sums of}\\ \text{squares for quadrats} - 2\text{ error cross products}\\ \text{of plots and quadrats}\end{array}\right]}{(N-1)\ (r-1)}$

and the other symbols have the same meaning as previously indicated.

The data for this part of the study are summarized in Table 2. The yield of the 1937 spring wheat test is very small due to severe damage from stem rust and hessian fly.

In only 2 of the 19 trials involving a comparison of quadrats and field plots was the interaction of variety$\times$method significant. The largest discrepancy between the two methods occurred in the 1938 barley trial where 5 of 14 varieties reacted differently. The year 1937 was a very unfavorable one for barley production at Madison. A wet spring delayed planting until the first week in May. A severe epidemic of stem rust resulted in shriveled grain. The degree of shriveling was more pronounced in some varieties than in others. In order to plant the same number of viable kernels per plot for each variety, the sowing rate for the variety was calculated based on percentage germination and weight per kernel. The resulting stands were thin in 1938, especially for certain varieties. The barley was also badly lodged which, with an uneven stand, resulted in considerable difficulty in harvesting the quadrats. This may explain in part the discrepancy in the varietal reaction for the two methods. In the 1938 winter wheat test 2 of 11 varieties tested reacted differently to the two methods. In all other trials the relative yields of the varieties for the two methods were essentially the same. This does not mean that in a particular trial the quadrat yield can be substituted for that of the entire plot for some of the varieties and not for others. An examination of the means for the two methods shows that in certain tests the yield when expressed in bushels per acre was higher for the quadrats while in other tests the reverse is true. For all tests the mean yields of the quadrats, field plots, and the rod rows were 35.0, 33.7, and 38.3 bushels per

TABLE 2.—*Comparison of the variety × method of testing interaction for quadrat, field plot, and rod-row plot methods of determining yields of small grains at Madison, Wis.*

Year	Number of varieties	Mean yield of grain per acre and coefficient of variability						Comparison of variety × method of testing interaction						F value	
		Quadrats		Field plots		Rod rows		Quadrats and field plots		Quadrats and rod rows		Field plots and rod rows			
		Mean, bu.	C.V.,* %	Mean, bu.	C.V., %	Mean, bu.	C.V., %	F value	N†	F value	N†	F value	N†	.05	.01
						Oats									
1937	10	50.7	8.2	45.6	9.8	52.5	14.9	0.7	0	1.6	0	2.3	0	2.1	2.8
1938	17	25.9	17.4	30.9	18.6	33.7	18.7	0.8	0	5.6	2	3.2	1	1.8	2.2
1939	15	44.6	18.3	44.8	18.1	57.5	13.7	0.4	0	3.1	2	3.8	2	1.8	2.3
1940	16	74.9	7.8	77.6	8.6	75.6	13.3	0.7	0	1.1	0	0.9	0	1.8	2.2
1941	15	73.4	10.8	69.1	12.6	59.6	14.5	1.3	0	4.7	3§	7.4	6§	1.8	2.3
1942	15	—	—	74.6	7.4	72.5	15.3	—	—	—	—	2.5	2	1.8	2.3
Mean‡		53.9	12.5	53.6	13.5	55.8	15.2								
						Barley									
1937	14	24.5	15.4	22.7	13.6	27.7	15.0	1.4	0	1.8	0	2.1	1	1.8	2.4
1938	14	30.1	10.2	26.0	11.0	42.6	14.5	8.6	5	4.0	1	1.4	0	1.8	2.4
1939	5	22.3	16.5	24.2	11.6	41.4	10.1	0.6	0	7.8	1	11.2	1	2.8	4.2
1940	5	41.6	13.8	43.7	11.0	44.7	10.8	2.0	0	1.5	0	2.8	0	2.8	4.2
1941	4	46.0	5.4	43.1	8.8	39.7	13.7	0.6	0	2.3	0	1.2	0	3.2	5.1
Mean		32.9	12.3	31.9	11.2	39.2	12.8								

Winter Wheat														
1938	11	37.8	7.9	29.6	8.0	35.8	13.9	2.8	2	0.7	0	2.5	1	2.0	2.6
1939	5	28.2	9.7	27.7	7.6	31.8	16.5	1.0	0	1.1	0	1.6	0	2.8	4.2
1940	10	37.2	16.8	35.4	13.3	39.8	13.9	0.1	0	0.9	0	0.9	0	2.1	2.8
1941	12	28.3	12.1	25.4	15.3	26.5	22.3	0.8	0	1.1	0	1.3	0	2.0	2.6
1942	11	—	—	38.8	8.1	41.3	12.0	—	—	—	—	1.7	0	2.0	2.6
Mean‡		32.9	11.6	29.5	11.1	33.5	16.7								
Spring Wheat														
1937	12	4.9	22.9	3.9	32.9	7.0	23.3	0.2	0	2.5	1	3.3	2	1.9	2.5
1938	9	22.0	9.6	21.3	8.7	22.0	14.7	0.9	0	7.4	2	7.9	2	2.2	3.1
1939	9	13.9	14.3	13.7	16.1	22.7	7.4	1.6	0	2.1	0	2.0	0	2.1	2.9
1940	9	32.0	11.5	32.9	8.1	43.2	10.4	0.1	0	2.3	0	2.7	0	2.1	2.9
1941	12	26.4	9.8	24.1	9.8	23.5	15.0	0.9	0	8.1	4	8.2	4	1.9	2.5
1942	8	—	—	29.2	8.0	30.0	11.9	—	—	—	—	2.2	0	2.2	3.1
Mean‡		19.8	13.6	19.2	15.1	23.7	14.2								
Mean for all crops‡		35.0	12.5	33.7	12.8	38.3	14.6								

*Coefficient of variability.
†Number of varieties significant at .01.
‡1942 data not included in Means.
§Explanation given in text.

acre, respectively. The mean coefficients of variability for the three methods were 12.5%, 12.8%, and 14.6%, respectively. Since quadrats were not harvested in 1942, the results from the 1942 rod rows and field plots are not included in the above means. The close agreement between the mean coefficient of variability for the quadrats and field plots indicates that the precisions of the two methods are essentially the same.

The F value for the interaction variety $\times$ method of testing was equal to or greater than the 0.5 level of significance for 14 tests out of 22 and for 11 tests out of 19, respectively, for the comparisons of the field plots and quadrats results with those of the rod rows. In most instances the significant F value was the result of one or two varieties which responded differentially for the testing methods compared. The number of individual varietal interactions which exceeded the .01 level of significance for the comparisons of field plots and quadrats with rod rows were, respectively, 16 out of 238 and 13 out of 204. The individual varietal interactions exceeding the .01 level of significance for the 1941 oat trial are not included for reasons explained later. The results indicate a good agreement for a large majority of the varieties tested when grain yields from field plots and quadrats are compared with those from rod rows.

In the 1941 oat trials six and three varieties, respectively, reacted significantly different in the field plots and the quadrats as compared to their reaction in the rod rows. A serious epidemic of crown rust, which was much more severe in the field plots than in the rod rows, occurred in 1941. Nine out of the 15 varieties compared were resistant to crown rust; the other six being susceptible. The differences in yields of the susceptible and resistant groups for the quadrats, field plots, and rod rows were, respectively, 39.4, 42.5, and 17.0 bushels per acre. The sums of squares for the interaction variety $\times$ method in the comparisons of both the field plots and quadrats with rod rows were separated into two parts, namely, the interaction of the two groups of varieties with methods and the interaction between varieties and methods within groups. The latter interaction in both comparisons was not significant.

Four of the 12 spring wheats compared in 1941 reacted differently in the rod rows than they did in the quadrats or 1/60-acre plots. No reason can be offered to explain this discrepancy, except that the field plots and rod-row plots were located in different fields. It is to be expected that certain varieties, when grown under slightly different environments of different fields, together with the effect of differences in type of plot, would react somewhat differently in respect to other varieties for the rod row and field plots.

COMPARISON OF PRECISION OF DIFFERENT NUMBERS OF QUADRATS PER FIELD PLOT

Under certain conditions it may be necessary or desirable to use quadrats to determined the yields of experimental plots. Where lodging is severe the harvesting of the entire plot may be considerably more costly and less accurate than an adequate number of quadrats.

For outlying experiments, where facilities are not available to harvest entire plots, quadrats may be used to advantage. The relative cost of the two methods of harvesting will depend principally upon the equipment available at a given station. At the University Hill Farms, Madison, Wis., the cost of harvesting and threshing the entire field plot is approximately twice that where four quadrats are taken from each plot. Where quadrats do not provide sufficient seed, it would be necessary to harvest one or more replicates of the entire plot. It is possible to increase the precision of the quadrat method in two ways, namely, by increasing the number of quadrats per plot or the number of replicates in the experiment.

Field experiments in which quadrats are harvested to represent the larger plot have two sources of random variation, the sampling and experimental errors. The sampling error is the random variation between quadrats within a plot. The experimental error is made up of two sources of variation, the random variation of plots within a replicate and the sampling error. These two sources of variation are independent of each other. The first of these variances is designated as A, while the second, the variance of the mean of k quadrats about the mean of the plot is B/k. The experimental error mean square in terms of plot means is, therefore, $A+\frac{B}{k}$, which on the basis of an individual quadrat would be $k\left(A+\frac{B}{k}\right)=k\,A+B$.

From a study of the composition of the two portions of the experimental error, using the procedure given by Snedecor (17), it is possible to estimate the relative efficiency of increasing both the number of quadrats per plot and the number of plot replications. The procedure followed was to obtain the estimated variance of a varietal mean on a single plot basis, $V_{\bar{x}}=\frac{kA+B}{kr}$, for different numbers of quadrats (k) and replications (r). The relative precision factor was calculated for several different combinations of quadrats and replications by dividing the $V_{\bar{x}}$ of that combination into the $V_{\bar{x}}$ where k and r were both equal to 4. The results are given in Table 3.

The data for the 1937 oat trial are used to illustrate the calculations discussed above.

Experimental error $(kA+B)$	$=70.68$	
Sampling error B	$=33.45$	
kA	$=37.23$	$A=9.31$

$$V_{\bar{x}} \text{ where } k=4, r=4 \text{ is} = \frac{70.68}{(4)(4)}=4.42$$

$$V_{\bar{x}} \text{ where } k=3, r=4 \text{ is} = \frac{3(9.31)+33.45}{(4)\,(3)}=5.12$$

$$\text{Relative precision factor is } \frac{4.42}{5.12}=86$$

TABLE 3.—*The estimated variances of varietal means and the relative precision factors for different numbers of replications and quadrats per plot based on field plots at Madison, Wis.**

Year	Mean square		Estimated variance of a plot A	Estimated variance of a varietal mean and relative precision factor										
	Experimental error† kA+B	Sampling error B		k=4; r=4 $V_{\bar{x}}$‡	k=3; r=4		k=6; r=4		k=8; r=4		k=6; r=3		k=3; r=5	
					$V_{\bar{x}}$	P.F.§	$V_{\bar{x}}$	P.F.	$V_{\bar{x}}$	P.F.	$V_{\bar{x}}$	P.F.	$V_{\bar{x}}$	P.F.
						Oats								
1937	70.68	33.45	9.31	4.42	5.12	86	3.72	119	3.37	131	4.96	89	4.09	108
1938	101.16	41.40	14.94	6.32	7.19	88	5.46	116	5.03	126	7.28	87	5.75	110
1939	267.66	36.21	57.86	16.73	17.48	96	15.97	105	15.60	107	21.30	79	13.99	120
1940	136.88	70.24	16.66	8.56	10.02	85	7.09	121	6.36	135	9.46	90	8.01	107
1941	251.34	102.78	37.14	15.71	17.85	88	13.57	116	12.50	126	18.09	87	14.28	110
Mean						89		116		125		86		111
						Barley								
1937	57.17	15.01	10.54	3.57	3.89	92	3.26	110	3.10	115	4.35	82	3.11	115
1938	38.31	5.34	8.22	2.39	2.50	96	2.29	105	2.22	108	3.04	79	2.00	120
1939	54.71	9.31	11.35	3.42	3.61	95	3.23	106	3.13	109	5.10	60	2.89	118
1940	131.49	58.94	18.14	8.22	9.45	87	6.99	118	6.38	129	9.32	88	7.56	109
Mean						92		110		116		77		116

Spring Wheat														
1937	5.06	1.96	0.78	0.32	0.36	89	0.28	114	0.26	123	0.37	86	0.29	110
1938	17.96	10.86	1.78	1.12	1.35	83	0.90	124	0.78	144	1.20	93	1.08	104
1939	15.74	4.80	2.74	0.99	1.09	90	0.89	111	0.84	118	1.18	84	0.87	114
1940	54.16	14.98	9.80	3.39	3.70	92	3.07	110	2.92	116	4.10	83	2.96	115
1941	27.18	13.54	3.41	1.70	1.98	86	1.42	120	1.28	133	1.89	90	1.58	108
Mean						88		116		127		87		110
Winter Wheat														
1938	35.81	25.87	2.49	2.24	2.78	81	1.70	132	1.43	157	2.27	99	2.22	101
1939	30.04	15.96	3.52	1.88	2.21	85	1.55	121	1.38	136	2.06	91	1.77	106
1940	157.44	29.60	31.96	9.84	10.46	94	9.22	107	8.92	110	12.30	80	8.37	118
1941	46.53	13.04	8.37	2.91	3.18	92	2.64	110	2.50	116	3.51	83	2.54	115
Mean						88		118		130		88		110
Mean for all crops.						89		115		124		85		112

*All numerical values in this table, save the precision factors, are in bushels per acre.
†Experimental error expressed on the basis of a single quadrat.
‡k = Quadrats, r = Replicate; $V_{\bar{x}}$ = Estimated variance of a varietal mean.

§P.F. = Precision factor.

The precision of the experiment can be increased by diminishing either or both portions of the experimental error. Before this is done it is desirable to express the two portions on a common basis so that their relative size may be readily ascertained as follows:

$$V_{\bar{x}} = \frac{kA+B}{r\,k} = \frac{A}{r} + \frac{B}{rk},$$

which for the 1937 oat trial is, $\frac{9.31}{4} + \frac{33.45}{16} = 2.33 + 2.09 = 4.42.$

Where A is small with respect to B, as is the case of the 1938 winter wheat, the precision of the experiment can be increased considerably by increasing the number of quadrats per plot. On the basis of this trial the estimated precision factor resulting from an increase of the number of quadrats per plot from four to six is 32%. This indicates that four replicates with six quadrats per plot would be slightly better than five replicates with four quadrats per plot. Where A is large in relation to B, as in the 1939 oat trial, the precision can be increased most rapidly by increasing the number of replications. In this case an increase in the number of quadrats per plot from four to six and to eight would give, respectively, increases in precision of 5% and 7%, whereas a reduction in number of quadrats to three and an increase in replicates to five would give a 20% increase in precision.

An examination of the relative precision factors for the several combinations of k and r given in Table 3 show considerable fluctuation from year to year within a crop. This indicates that it would be undesirable to make a recommendation based on the results of a single test. A comparison of the average precision factors for the different cereals shows a very close agreement, especially for the oats, spring wheat, and winter wheat. For the barley the data indicate that increasing the number of replicates would be relatively more effective than increasing the number of quadrats per plot as compared to the other crops. The estimated relative precision factor for different numbers of quadrats per plot and replications per trial are shown graphically in Fig. 1. These values are based upon the mean relative precision factors for all crops given in Table 3. Since the estimated variance of a varietal mean is given by $\frac{kA+B}{kr}$, the relation between A and B was obtained from:

$$\frac{4A+B}{16} = 100$$

$$\frac{3A+B}{12} + \frac{6A+B}{24} + \frac{8A+B}{32} + \frac{6A+B}{18} + \frac{3A+B}{15} = 100\left(\frac{100}{89} + \frac{100}{115} + \frac{100}{124} + \frac{100}{85} + \frac{100}{112}\right)$$

Accordingly, A = 243.96 and B = 624.16. The relative precision factor, expressed in percentage of r = 4, k = 4 as 100, was obtained for

different combinations of r and k by solving the equation $X = \dfrac{100}{\dfrac{kA+B}{kr}}$

which for k = 5 and r = 4 is $\dfrac{100}{\dfrac{5(243.96)+624.16}{20}} = 108.$

The relative precision factors based on all 19 trials show that an increase in the number of replications would be more effective than an increase in the number of quadrats per plot. If a total of 24 quadrats are to be harvested, the estimated relative precision for the combinations of r = 2 and k = 12, r = 3 and k = 8, r = 4 and k = 6, and r = 6 and k = 4 are, respectively, 68, 93, 115, and 150. In any comparison of the above values the increased cost resulting from an increase in the number of replications must be considered.

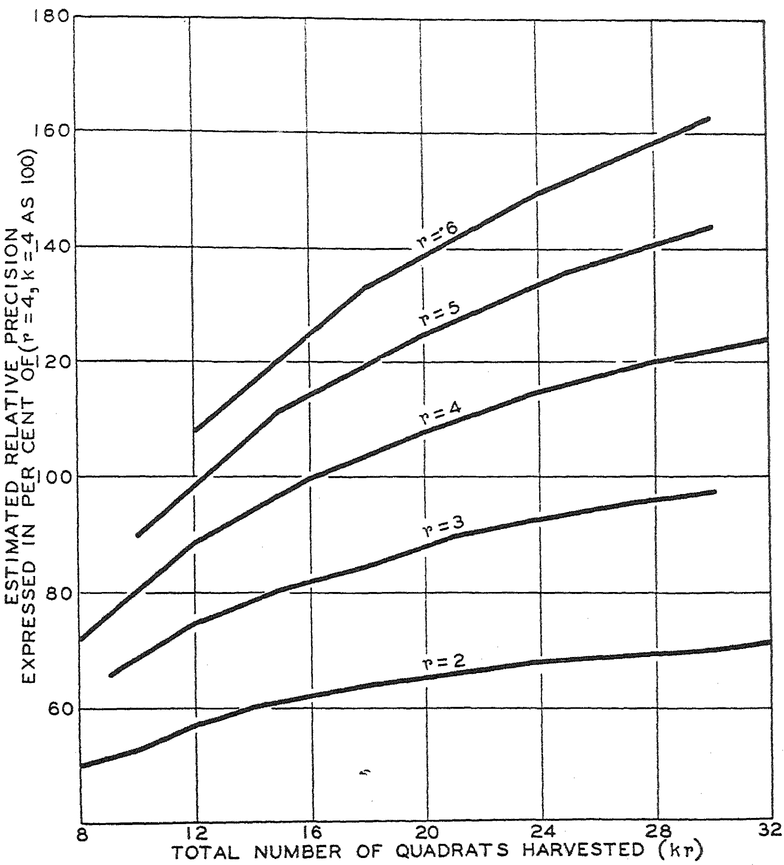

FIG. 1.—Estimated relative precision for different number of replicates and quadrats per plot expressed in percentage of the value for four replicates and four quadrats per plot as 100, based on data from field plots at Madison, Wis.

The data in Table 2 show that the coefficients of variability for the quadrats and the field plots were similar. This indicates that the use of four quadrats gave essentially as precise information as harvesting the entire plot. On the basis of the results in Table 3 the precision of a test can be increased 25% by using five replicates with four quadrats per plot or four replicates with eight quadrats per plot. The procedure to be recommended to increase precision depends largely upon cost factors and the availability of land. If land is not the limiting factor and the cost of an additional replication is less than that of doubling the number of quadrats per plot, it would be advisable to plant an additional replicate. However, if land is limited or if increasing the number of quadrats is more economical than increasing the number of replicates, eight quadrats with four replicates would be recommended. The ultimate answer to the question would depend largely upon the characteristics peculiar to the experiment station concerned.

SUMMARY

1. The precision of the lattice design, with and without recovery of inter-block information, as compared to the randomized complete block design was determined for 22 small grain trials. The average of all tests gave an increase of 9% in precision with recovery of inter-block information and a loss of 8% when inter-block information was ignored.

2. Four quadrats harvested from 1/60- or 1/80-acre field plots provided, for the most part, reliable estimates of the yield of the entire plot. The precision of the quadrats as measured by the coefficient of variability is essentially the same as that of the field plots.

3. A good agreement was found for most of the varieties tested when grain yields from rod-row plots were compared with those from field plots and quadrats.

4. Calculations based on the 19 field plot trials showed that increasing the number of replications would be more effective than increasing the number of quadrats per plot as a means of increasing precision.

5. The average precision factors calculated for different numbers of quadrats and replicates were essentially the same for the different cereals, especially for oats, spring wheat, and winter wheat.

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BORDER EFFECT IN SOYBEAN NURSERY PLOTS[1]

A. H. PROBST[2]

ONE of the most important factors in connection with breeding soybeans is the accurate evaluation of new strains in the yield-testing program. This is especially true when testing strains in which there is not much spread in the yields. Published data on plot technics with this crop are very limited.

In an effort to evaluate some of the present plot technics used in soybean testing, a study of border effect was undertaken at Lafayette, Ind., by the U. S. Regional Soybean Industrial Products Laboratory[3] and Purdue University Agricultural Experiment Station[4] cooperating, with four varieties of soybeans. The work was conducted over the 4-year period from 1938 to 1941, inclusive.

The data of Arny and Hayes (1)[5] show increases in yield resulting from border effect from only the sides of plots which varied from 7.9 to 15.3% with an average of 12.5% in oats, from 14.1 to 23.7% with an average of 18.4% in wheat, and from 21.1 to 45.8% with an average of 26.3% in barley. They observed a rearrangement in yield rank due to border effect and decided to remove the plants from an area at least 1 foot wide within the margins of variety test plots to obliterate border effect.

Love and Craig (3), in discussing cereal breeding methods, state that, "It is obvious that if the end of each row is cut off, more nearly uniform conditions may be obtained and the effect of increased nutrition which occurs at the ends will not enter into the calculations and modify the results."

McClelland (4) shows increases in yield of 8.3%, 8.5% and 7.4%, respectively, for winter oats, winter wheat, and spring oats due to border effect. He concluded that removing or including the border rows made little difference in the comparison of yields.

From the data obtained by McRostie and Hamilton (5) with grasses and legumes they concluded that, "The inclusion of the border foot in plats surrounded by cultivated paths is associated with inaccuracy of result". Their data on yields of individual plants of western rye grass show increases ranging from 5.87 to 54.11% attributed to border effect.

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[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, and Bureau of Agricultural and Industrial Chemistry, U. S. Regional Soybean Industrial Products Laboratory, U. S. Dept. of Agriculture, and Purdue University Agricultural Experiment Station, Lafayette, Indiana, cooperating. Received for publication September 4, 1942.

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[3]A cooperative organization participated in by the Bureaus of Agricultural and Industrial Chemistry and Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, of the U. S. Dept. of Agriculture, and the Agricultural Experiment Stations of the North Central states of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin.

[4]Journal paper No. 22, Purdue University Agricultural Experiment Station.

[5]Figures in parenthesis refer to "Literature Cited", p. 666.

Hollowell and Heusinkveld (2), working with alfalfa and red clover, state that, "To discard the two rows next to the alley at harvest would minimize border effect as a source of error in securing yields from experimental plats".

MATERIALS AND METHODS

In order to determine (a) border effect in soybean nursery rows and (b) the resulting grain yields which might be obtained from trimming rows at maturity compared to trimming soon after emergence, the Mukden, Mandell, Dunfield, and Illini varieties were used. Mukden is the earliest of these varieties in maturity and Illini the latest at Lafayette, Ind. The study was conducted on a Brookston-Crosby soil complex.

A split-plot Latin square design was used with four replications of each variety. Excessive amounts of seed of each variety were planted in single row plots 20 feet long with 30 inches between rows. Each row was trimmed to exactly 18 feet in length after the plants emerged and the plants were thinned in the row to approximately 1 inch apart. Alleys 3 feet wide remained after trimming.

The border effect within the rows was determined by removing four successive sections of plants from each end of each 18 foot row. The sections were 6 inches in length. The seed from the outer 6-inch sections from each end of a row were combined and designated as section one, the successive sections in order were treated similarly and, respectively, designated as section two, three, and four. Thus each section contained the quantity of seed from a linear foot of row.

The method used to obtain the grain yields from rows trimmed soon after emergence compared to those obtained when the rows were trimmed at harvest consisted of adding the weight of the seed from the two outer sections, one and two, to the weight of seed obtained in the 14-foot row length remaining after the four sections were removed. This is designated as trimmed at emergence. In a similar manner the seed weight obtained from sections three and four was added to the weight of the seed obtained in the 14-foot row. This is designated as trimmed at maturity.

EXPERIMENTAL RESULTS

DETERMINATION OF BORDER EFFECT

The data in Tables 1 and 2 show that there is considerable border effect on the ends of the rows, particularly in section one which yields highly significantly greater than any other section. No significant difference in weight of seed was obtained within varieties between sections three and four in any year, or in the summary for the 4-year period. The yields have averaged somewhat higher in section four than in section three. There is not always a significant difference between sections two and three or between two and four. In 1939 and 1940 section two was not significantly higher in yield than either section three or section four with any variety. Section two of the Mukden variety did not yield significantly more than sections three or four in any single year or in the mean of the four years. In two years section three or four outyielded section two. It appears that Mukden does not respond as much to border effect as the other varieties.

TABLE 1.—*The mean weight of seed obtained from different 1-foot sections of soybean nursery rows with four varieties of soybeans during 4 years, 1938–41, at Lafayette, Indiana.*

Varieties	Four-year mean weight in grams*			
	Section one	Section two	Section three	Section four
Illini	165.0	68.1	45.5	55.8
Mandell	151.3	76.4	56.2	50.5
Dunfield	158.1	63.3	43.6	50.6
Mukden	137.4	58.0	51.8	52.6
Section means†	153.0	66.4	49.3	52.4

Analysis of Variance

Source of variation	Degrees of freedom	Mean squares
Years	3	6,365.00**
Varieties	3	1,110.67
Varieties × years	9	699.22**
Error (a)	24	88.00
Sections	3	153,986.33**
Sections × years	9	1,472.56**
Sections × varieties	9	906.00**
Sections × varieties × years	27	380.33
Error (b)	144	349.97

*A difference of 21.2 grams is significant between varieties within sections; a difference of 13.1 grams is significant between sections within varieties.
†A difference of 6.5 grams is significant between means of sections.
**Highly significant differences.

TABLE 2.—*The mean weight of seed in grams obtained from four different sections of soybean nursery rows by individual years for four varieties of soybeans.*

Year	Section one	Section two	Section three	Section four	Difference necessary for	
					Significance	High significance
1938	183.8	80.7	57.8	52.9	12.1	16.3
1939	150.4	62.2	46.2	61.8	19.0	25.6
1940	130.6	58.6	45.1	45.3	10.7	14.4
1941	147.2	64.3	48.0	49.5	9.5	12.7
Mean	153.0	66.4	49.3	52.4	6.5	8.6

From these data it is evident that border effect may be eliminated by removing a foot section from each end of the row at maturity. It is likewise evident that all varieties do not respond the same in production on the ends of the rows.

YIELDS OBTAINED BY END TRIMMING AT EMERGENCE AND AT MATURITY

The results for the mean of the 4-year period are shown in Table

3, and the results of the combined varieties for individual years appear in Table 4.

TABLE 3.—*Four-year summary, 1938–41, of the effect on yield from trimming soybean nursery plot rows soon after emergence and at maturity.*

Varieties	Trimmed after emergence		Trimmed at maturity		Difference between treatments	
	Bu. per acre	Rank	Bu. per acre	Rank	Bu. per acre	Percentage
Illini..........	37.5	1	32.0	2	5.5	17.2
Mandell.......	37.2	2	32.6	1	4.6	14.1
Dunfield......	35.4	3	30.0	4	5.4	18.0
Mukden......	34.8	4	30.6	3	4.2	13.7
Means........	36.2		31.3		4.9	15.7

TABLE 4.—*Mean yields in bushels per acre by individual years of the effect on yield from trimming soybean nursery rows soon after emergence and at maturity with four varieties of soybeans.*

Years	Trimmed after emergence	Trimmed at maturity	Difference between treatments	
			Bu. per acre	%
1938............	42.0	35.0	7.0	20.0
1939............	36.4	32.2	4.2	13.0
1940............	31.1	27.1	4.0	14.8
1941............	35.4	30.8	4.6	14.9
Treatment means	36.2	31.3	4.9	15.7

All varieties yielded considerably higher when trimmed at emergence than when trimmed at maturity in each of the individual years, as well as for the average of the 4 years. There was considerable fluctuation in the percentage increase in yield due to border effect between varieties within individual years as well as within varieties in different years, as shown in Table 5. Mandell and Mukden, in all cases but one, gave smaller increases in each year than Dunfield and Illini, which might indicate a differential foraging ability between the different varieties. There might also be some association with

TABLE 5.—*Percentage increase due to border effect for each variety, 1938–41.*

Varieties	1938	1939	1940	1941	Mean
Illini..............................	21.5	17.1	16.7	13.9	17.3
Mandell..........................	15.3	10.6	13.9	15.4	13.8
Dunfield..........................	23.2	14.4	17.5	17.6	18.2
Mukden..........................	21.2	10.6	10.2	12.8	13.7
Mean............................	20.0	13.2	14.6	14.9	15.7

time of maturity in that the latter varieties are a few days later. Mukden branches the least, but there is no especially noticeable difference in the other three varieties. Even though there are appreciable differences in percentage increase between varieties, as shown in Table 5, these differences are quite small on an acre yield basis, as shown in Table 3. There is a rearrangement in yield rank under the two systems.

From these data it is observed that yields are lower when the rows are trimmed at maturity than when an accurate row length is established soon after emergence. The former method in all probability more nearly approximates the actual yields of varieties under field conditions than the latter method. It is also seen that on the basis of the percentage increases in yield due to border effect varieties do not react the same. The small differences in the actual yields do not warrant concluding, from the varieties worked with and the methods employed, that one system is better than the other. It is well to keep in mind, however, that trimming at maturity assures one of a constant row length, whereas in trimming at emergence the rows might vary due to the hazards encountered during the growing season. Likewise, data without border effect removed might be considered questionable if presented to farmers in that as a group farmers are more concerned with actual field results than with relative yields.

CONCLUSIONS

Border effect is very evident among the plants in the outer foot of soybean nursery rows adjacent to 3-foot alleys. This effect may be eliminated by removing the outer foot of row length of plants at maturity.

Yields were on the average 16% higher in single-row soybean nursery plots 16 feet long and 30 inches between rows when border effect was not removed.

Varieties responded differently with respect to border effect but not enough to give a marked change in the relative yields.

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MATURITY MEASUREMENTS IN CORN AND AN INDICATION THAT GRAIN DEVELOPMENT CONTINUES AFTER PREMATURE CUTTING[1]

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ATTENTION given to maturity measurements in corn and means for comparing relative maturities among strains has increased considerably since it has become necessary in modern testing programs to evaluate large numbers of hybrid combinations. Relative maturities of corn hybrids must be accurately determined in order to measure their relative yielding abilities (19).[3]

Percentage of dry matter or moisture in the grain has received most attention as a measurement of maturity. Several workers have reported moisture values at which they considered the grain development to be completed, as follows:

Year reported	Investigator	Crop	Moisture at maturity, %
1920	Harlan (5)	Barley	42.0
1923	Olson (12)	Wheat	40.0
1930	Burnett and Bakke (3)	Wheat, oats, and barley	Below 40.0
1934	Robinson (14)	Corn	40.0 (air-dry)
1938	Ohio Agr. Exp. Sta. (11)	Wheat and oats	40.0
1939	Lambert (10)	Corn	37.5
1940	Rather and Marston (13)	Corn	40.0

Yield losses resulting from premature harvesting have been pointed out by Shelton and Cottrell (17) and by Schweitzer (16). Kiesselbach and Lyness (9) reported yield reductions of 7.4% and 10.4%, respectively, when Kherson oats were harvested 4 and 6 days prior to "maturity". Hopper (7) found 68.7%, 98.9%, and 100% of the maximum dry weight in the grain of corn in the dough, glazed, and ripe stages, respectively. Lambert (10) calculated that corn at 75% moisture had produced 15% of its maximum grain yield, at 55% moisture 74%, and at 45% moisture 91% of the maximum yield. Corn harvested at 50% moisture in the grain yielded 10 to 20% less than at 40% or below according to Rather and Marston (13).

Authors do not agree on the translocation of materials into the grain after plants have been cut. Kedzie (8), Briggs (2), Teller (20), Davenport and Frasier (4), and Harlan and Pope (6) found increases in kernel weights of cereal crops when harvested prematurely and dried on the culms.

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[3]Figures in parenthesis refer to "Literature Cited", p. 680.

Arny and Sun (1) and Wilson and Raleigh (22) reported no appreciable increases in wheat or oats regardless of the stage of development when cut or the method of drying. An Ohio Agricultural Experiment Station report (11) stated that, "The yield of corn will be reduced if it is cut before the well glazed stage . . . . Corn does not ripen in the shock, it merely dries out."

The term "maturity" has not been clearly defined nor consistently used in the literature. It has, however, been expressed more definitely in recent years, usually in moisture content of the grain. Throughout this paper "maturity" is defined as the point at which maximum grain development is first attained. "Relative maturity" expresses the comparative periods required for strains to reach maximum dry weight of grain.

This paper compares several possible criteria of relative and actual maturities in corn. In addition, data are presented which indicate that grain development continues for a time after corn is prematurely cut and shocked, a common farm practice in Ohio as shown by surveys conducted in 1940 and 1941, and reported in this paper.

MATERIALS AND METHODS

MEASUREMENTS OF MATURITY

Ten strains of corn, nine commercial yellow dent hybrids and one open-pollinated variety, with a wide range in lengths of growing season, were planted May 21, 1939, at Kenton, Ohio, in four randomized blocks with plots 2×10 hills in size. The same strains were planted in 2×20 hill plots at Columbus, Ohio, on the Agronomy Experiment Farm in 1940 and 1941. Four blocks were planted early in May (May 7, 1940, and May 2, 1941) and four additional blocks planted somewhat later (June 3, 1940, and May 26, 1941). Six kernels were planted and plants were later thinned to uniform stands of three per hill.

Numbers of plants having exposed silks were recorded on alternate days during the silking periods, and mid-silking dates were determined from these data.

All ears from two hills, one selected at random in each row of the plot, were harvested at 4-day intervals during the latter part of the development period of the grain. Composite samples of grain were obtained by shelling four to six rows of kernels from each ear, the number being constant for the ears in a sample. Three rows had previously been removed and discarded, two by means of a screw driver and the third by hand shelling. This was especially necessary in the early harvests to obtain unbroken kernels for the moisture and kernel weight determinations. Shelled samples were placed immediately in moisture-proof envelopes and taken to the laboratory.

Samples were weighed, placed in cloth bags, dried at 65° to 75° C 4 days, and at 85° to 95° C another 4 days. Approximately 1% of moisture remained at the end of this drying treatment. The dried samples were weighed and grams per 100 kernels were determined by averaging the weights of triplicate 100 kernels samples which had been weighed on a torsion balance accurate to 0.01 gram. Plants and ear husks were described and the ears harvested were classified into the following groups in 1940 and 1941:

1. *Early milk.*—Kernels pale yellow in color and not yet maximum size.
2. *Late milk.*—Kernels much deeper yellow in color and having attained maxi-

mum size. Kernels rounded to 20% dented. Average dry matter content of the grain, 40%.

3. *Soft dough.*—20 to 90% of the kernels denting but still easily punctured with the thumbnail. Average dry matter, 50%.

4. *Hard dough.*—Kernels more than 90% dented and difficult to puncture with the thumbnail. Ears remained in this class as long as any milk was present in the bases of kernels opposite the germ faces. Average dry matter, 60%.

5. *Ripe.*—Kernels fully dented and no milk in the bases. Dry matter, 70% or above.

Ear appearance factors from 1 to 5 were calculated for each plot on the basis of the number of ears classified into the five groups described above.

KERNEL DEVELOPMENT IN SHOCKED CORN

The cutting and shocking study was not planned until near harvest time in 1941 and it was therefore necessary to utilize material which had been planted for other purposes. Ten-hill sections of rows in Iowa 939 and Ohio C 84, and one single-cross hybrid, (Ohio 26×Ohio 51) were cut and shocked at 4-day intervals and tied into two bundles each consisting of five alternate hills. Immediately after cutting, the ears in one of the bundles were sampled in the manner described in an earlier paragraph with the following alterations: (a) They were not removed from the stalks, (b) only a narrow strip of husks was pulled back and later replaced, and (c) only two rows of kernels were shelled from each ear for the composite sample.

Both five-hill bundles were then placed in the center of a small shock of corn. Eight days later the shock was torn apart and all ears in both bundles were sampled. This procedure provided duplicate bundles one of which was sampled only after drying in the shock, and the other sampled both before and after drying. Percentages of dry matter in the grain and weights per 100 kernels were determined as previously outlined.

TIME OF CUTTING CORN IN OHIO

Surveys covering several sections of Ohio were made in 1940 and 1941 to determine the stages of development at which corn was cut and shocked on farms. Composite samples were obtained from the ears of 20 to 25 representative plants in fields which were being cut. Percentages of dry matter were determined by weighing before and after drying for 8 days at 85° to 95° C.

DATA AND DISCUSSION

DAYS TO SILKING

Table 1 gives the number of days from seedling emergence to mid-silking date and from mid-silking to maturity (65% dry matter in the grain).

Strains are listed in Table 1 in order of maturity, the earliest first, on the basis of the dry matter in the grain at harvest (average of the 3 years). It is apparent from the data that silking date is highly indicative of relative maturity. The correlation coefficients between days from seedling emergence to silking and the percentage of dry matter in the grain at harvest time varied from −0.528 to −0.873 for the 1941 harvests, with "r" at the 1% level equal to ±0.418. How-

TABLE 1.—*Days from seedling emergence to mid-silking date and from mid-silking to 65% dry matter in the grain, Columbus, Ohio, 1941.**

Strains in order of maturity†	Planted May 2		Planted May 26		Average silking to 65% dry matter, days
	Emergence to silking, days	Silking to 65% dry matter, days	Emergence to silking, days	Silking to 65% dry matter, days	
Ohio M15	62.0	48.0	59.5	47.5	48.0
Ohio K23	61.0	49.0	59.0	51.0	50.0
Ohio K35	62.0	51.0	59.5	53.5	52.0
Woodburn	62.0	53.0	59.0	52.0	52.5
Iowa 939	63.0	52.0	61.0	53.0	52.5
Ohio W17	65.0	51.0	62.0	50.0	50.5
U. S. 65	66.0	50.0	62.0	52.0	51.0
Indiana 614	66.5	51.5	63.0	55.0	53.0
Ohio C84	68.0	53.0	64.0	54.0	53.5
U. S. 13	68.0	54.0	63.0	57.0	55.5
Significant differences:					
5% level	0.4		0.6		
1% level	0.5		0.8		

*Each figure for number of days is the average of 4 plots.
†Relative maturity based on 3 year average percentages of dry matter in the grain at harvest.

ever, small differences in maturity cannot be predicted from differences in silking date. Ohio M15 silked at the same time as Ohio K 35 and Woodburn and 1 day later than Ohio K 23, but was distinctly earlier than these on the basis of dry matter in the grain (Table 2).

Snelling and Hoerner (18) reported a significant correlation between silking date and percentage of dry matter in the grain on September 14, but an insignificant correlation on October 12. In the present investigation, similar correlation coefficients were calculated for all harvests in two plantings. They decreased steadily from the early to the late harvests in one planting, but no definite trend was found in the second.

PERCENTAGE OF DRY MATTER IN THE GRAIN

Moisture in the grain has been widely used by research workers during recent years for measuring both relative and actual maturities in corn. In this investigation the percentage of dry matter was calculated rather than the moisture because a curve rising toward maturity seemed preferable to one decreasing and it could also be more readily graphed with the corresponding kernel weights.

Table 2 presents the dry matter percentages of the grain for the two dates of planting in 1941. Differences required for significance are given and their magnitudes indicate that the sampling technic was adequate for plots of this size.

Typical dry matter curves for the three years are given in Figs. 1 to 3. The effect of weather is strikingly illustrated in Fig. 1 on which

TABLE 2.—*Percentage dry matter in the grain of corn, Columbus, Ohio, 1941.*

Strain	Planted May 2													
	Aug. 4	Aug. 8	Aug. 12	Aug. 16	Aug. 20	Aug. 25	Aug. 29	Sept. 2	Sept. 6	Sept. 10	Sept. 15	Sept. 19	Sept. 23	Sept. 27
Ohio M15	32.3	37.5	47.1	51.7	56.0	61.4	64.0	67.8	72.1	73.8	79.0	79.7	82.8	—
Ohio K23	26.8	38.0	45.6	48.0	54.0	61.0	64.5	67.4	68.7	72.6	78.7	79.2	80.3	—
Ohio K35	26.7	33.6	39.9	45.4	49.0	56.0	63.0	65.2	67.8	72.3	74.6	77.9	81.4	—
Iowa 939	25.4	33.6	39.0	44.4	48.5	55.3	59.2	65.8	67.8	68.4	73.2	76.5	79.1	—
Ohio W17	20.8	27.7	37.7	41.0	47.4	52.9	57.8	63.6	65.5	67.8	73.6	77.0	80.8	—
Woodburn	28.2	34.4	44.0	46.2	51.9	57.0	57.6	65.2	63.9	70.6	73.3	74.0	81.0	—
U.S. 65	—	—	38.2	41.9	48.4	53.3	58.6	62.4	66.5	70.3	74.6	76.6	80.2	79.2
Ind. 614	—	—	35.2	39.0	43.2	49.1	54.2	60.4	64.2	67.8	70.1	73.5	75.8	78.0
Ohio 84	—	—	—	35.6	42.7	47.6	50.4	58.2	61.4	64.9	69.2	72.4	76.6	77.0
U.S. 13	—	—	—	36.4	42.0	47.6	51.8	55.9	60.0	65.2	68.6	71.8	74.8	75.0

Significant difference, 5% level, 1.5% dry matter
Significant difference, 1% level, 2.0% dry matter

Strain	Planted May 26											
	Aug. 25	Aug. 29	Sept. 2	Sept. 6	Sept. 10	Sept. 15	Sept. 19	Sept. 23	Sept. 27	Oct. 1	Oct. 6	Oct. 10
Ohio M15	33.8	39.6	46.1	51.9	58.9	64.3	67.4	70.5	71.9	75.4	74.7	76.2
Ohio K23	27.9	37.5	43.6	50.9	57.0	60.6	67.1	67.4	71.8	73.4	74.9	75.3
Ohio K35	26.8	34.2	40.8	45.7	50.7	57.4	61.2	67.6	70.2	73.8	72.3	75.7
Iowa 939	27.6	32.6	38.4	42.7	50.8	56.9	60.9	65.4	67.0	75.1	70.8	72.6
Ohio W17	24.4	31.9	37.1	43.6	51.4	58.5	62.1	67.3	69.0	75.0	71.6	74.8
Woodburn	29.7	35.1	43.0	50.5	51.5	58.2	65.0	67.3	70.4	74.1	73.2	74.9
U.S. 65	—	—	41.3	47.3	51.8	56.9	61.2	64.7	68.4	72.7	71.2	74.7
Ind. 614	—	—	—	43.5	47.5	53.0	59.3	60.9	64.6	69.0	69.2	70.5
Ohio 84	—	—	—	39.6	45.5	51.2	55.8	61.4	65.0	70.3	67.7	71.0
U.S. 13	—	—	—	42.2	45.1	51.4	57.6	58.9	63.8	66.6	66.0	70.1

Significant difference, 5% level, 1.7% dry matter
Significant difference, 1% level, 2.3% dry matter

pertinent temperature and rainfall data are given. A prolonged drouth preceded the August 28 and September 2 harvests, with the result that 0.47 inch of rainfall on September 4 caused a definite interruption in the rising curve of dry matter in the grain. A similar break occurred after the September 14 harvest which had been preceded by two days of high temperatures and low humidity. Dry matter curves for 1940 rose steadily and the same is true of 1941, except for the period between October 1 and 6 when rain fell daily.

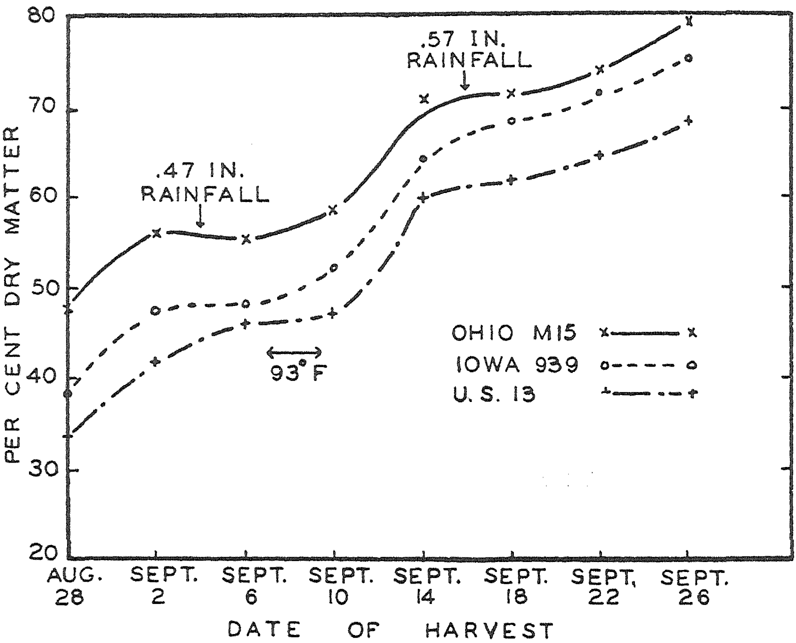

FIG. 1.—Dry matter in the grain of corn planted at Kenton, Ohio, May 21, 1939.

The average increase of dry matter over the entire harvest periods for all strains and all plantings was approximately 1% per day but varied among the three years as follows: 1939, 1.3%; 1940, 0.9%; and 1941, 1.1%. From the time of the first harvest until the maximum kernel weight was reached, the increase was 1.1% per day, and it averaged about 0.6% per day over the remainder of the harvest period.

Differences among the strains in the rates of dry matter increases were not found. However, it would appear that differences existed prior to the time harvesting began inasmuch as Ohio M 15 silked 1 day later than Ohio K 23 in 1941 but was considerably higher in dry matter at the earliest harvest dates. The same is true of U. S. 65 when compared with Iowa 939. Since differences in drying rates were not found during the harvest periods (grain contained 30 to 80% dry matter), it appears that the percentages of dry matter in the grain at harvest may confidently be used to measure relative maturities among strains.

POINT AT WHICH TRANSLOCATION CEASES

An average for the percentage of dry matter in the grain at which the translocation of materials into the kernels ceased was obtained by superimposing dry matter curves (Figs. 1 to 3) upon the corresponding curves for oven-dry weights per 100 kernels (such as Fig. 5). Some of the strains had not reached their maxima at the time of the last harvest and therefore could not be included in the determination of the average figure. The average dry matter in the grain at which translocation ceased (48 values in five plantings) was 66.2%. A check on the drying technic showed that slightly over 1% of moisture re-

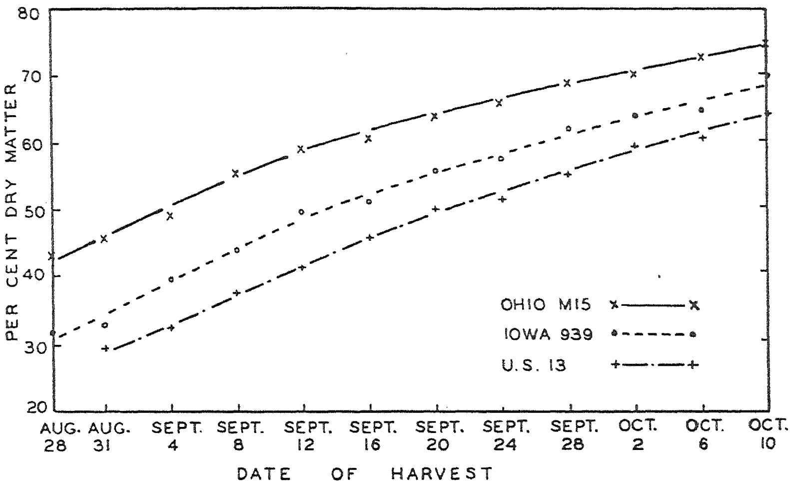

FIG. 2.—Dry matter in the grain of corn planted at Columbus, Ohio, June 3, 1940.

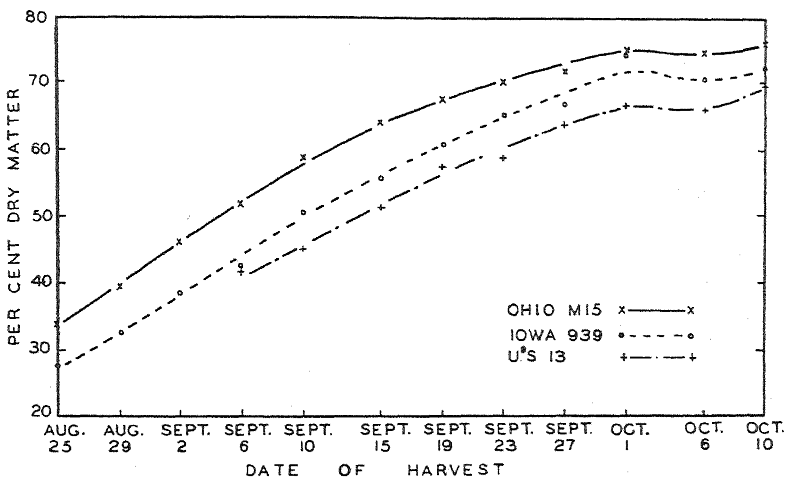

FIG. 3.—Dry matter in the grain of corn planted at Columbus, Ohio, May 26, 1941.

mained after drying so that the corrected value was approximately 65%, or about 5% above the values given by other investigators except Lambert (10). This difference may possibly be attributed to different drying technics which were not always fully described by the authors.

Data obtained indicate that the yield of a plot of corn continues to increase until the dry matter in the grain averages 65%, or the moisture falls to 35%. Translocation into the individual kernels, however, must have ceased at some point below 65% dry matter because this was an average value for the entire sample which included kernels from ears well beyond maturity which would raise the average dry matter above that for the kernels from ears just at the maturity point.

Fig. 4 shows the percentages of maximum kernel weights attained at different levels of dry matter. If future investigation shows that the grain normally increases after corn is cut and shocked, as is suggested elsewhere in this paper, the curve in Fig. 4 should be corrected to compensate for increases found to occur at different moisture levels.

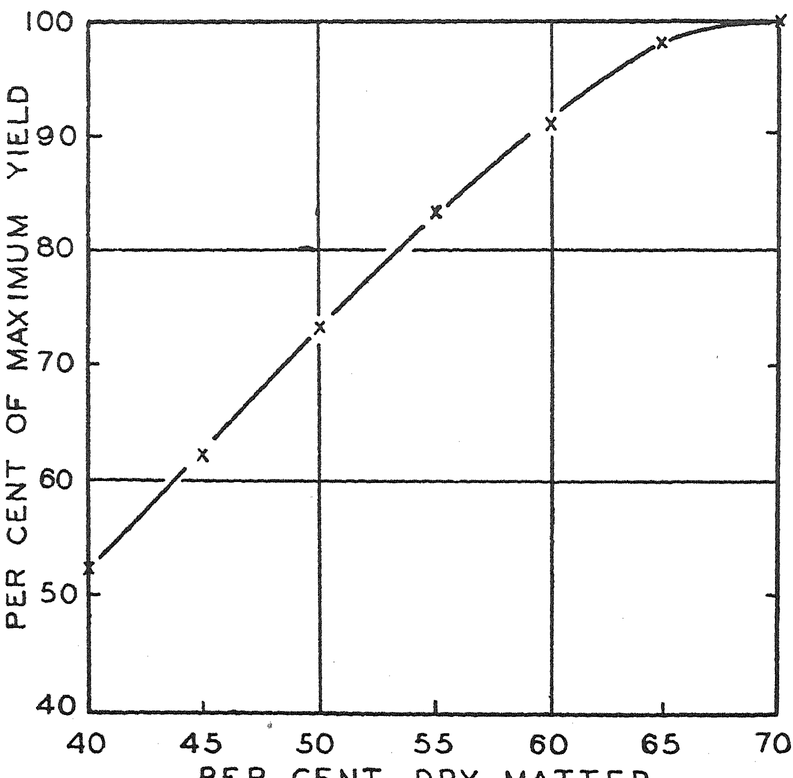

FIG. 4.—Percentage of maximum yield of corn at successive levels of dry matter in the grain. Data are for 1940 and 1941 and are not corrected for increases that may normally occur in the grain of shocked corn.

WEIGHT PER 100 KERNELS

Typical developmental curves for three strains are given in Fig. 5. Temperature and rainfall which altered the course of the percentage of dry matter had little noticeable effect on the kernel weight curves. An increased error in sampling, noted also by Sayre and Morris (15), was evident toward the end of the season in several of the curves, although it does not show in Fig. 5.

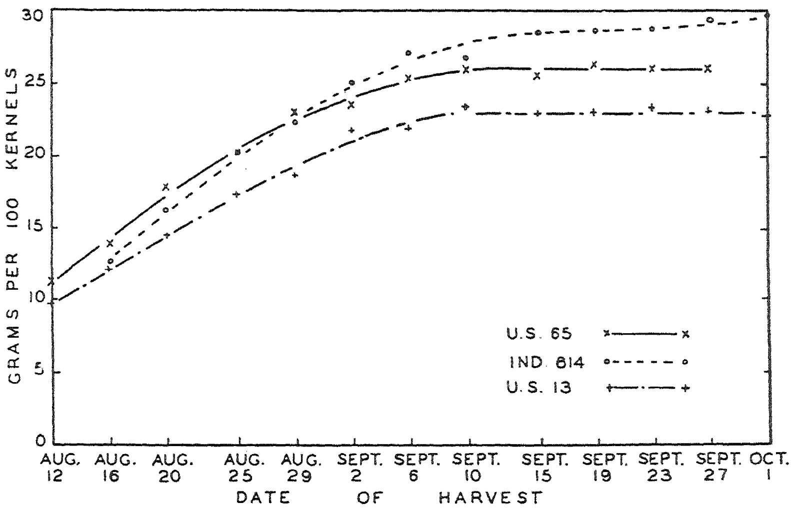

FIG. 5.—Development of the grain in three corn hybrids planted at Columbus, Ohio, May 2, 1941.

EAR APPEARANCE

It is often desirable to estimate the moisture content of the grain of corn during the growing season, and it is especially important to have satisfactory means for describing corn at the time kernel development is completed.

An attempt was made to meet these needs by ranking the ears in 1940 and 1941 on the basis of external appearance into the five groups described under materials and methods. Correlation coefficients between the ear appearance factors and the percentages of dry matter in the grain were +0.953, +0.971, and +0.966 in the June 3, 1940, May 2, 1941, and May 26, 1941 plantings, respectively. These correlations show that it was possible to estimate rather accurately the dry matter in the grain of corn by the method outlined.

The approximate percentages of dry matter corresponding to the ear appearance factors were: 2, late milk, 40%; 3, soft dough, 50%; 4, hard dough, 60%; and 5, ripe, above 70%. An ear appearance factor of about 4.4 corresponded to the point of 65% dry matter in the grain. Maturity, then, was reached when one-third to one-half of the ears in a plot were in the ripe stage and the remainder were in the hard dough stage.

PLANT APPEARANCE AND DRY EAR HUSKS

Plant appearance on each harvest date was noted in 1940 and 1941, and in the latter year the number of dry ear husks per plot was also counted. The number of dead leaves at a given level of moisture in the grain differed greatly between the two years and therefore the appearance of the plant is not considered a satisfactory basis on which to estimate the development of grain.

The time at which the ear husks died or turned straw colored appeared to be more characteristic of the strains and less dependent upon weather conditions than was the appearance of the leaves. Fig. 6 shows the time and rate at which the ear husks died on 6 of the

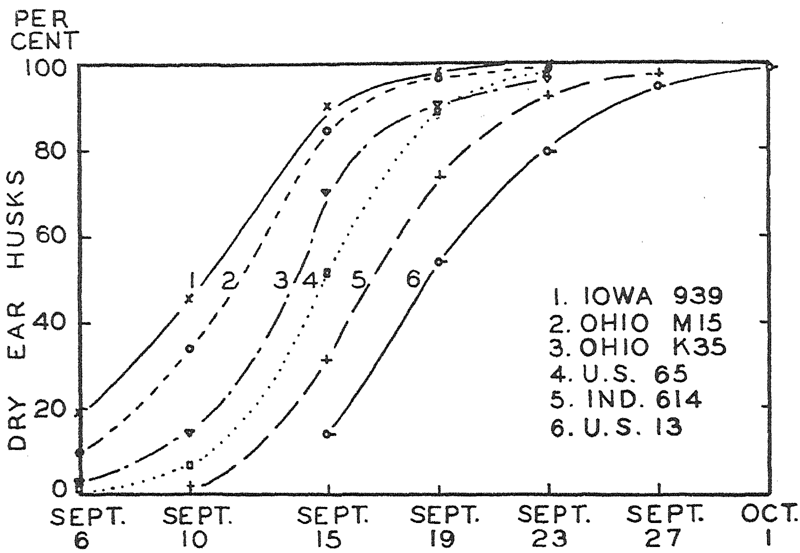

FIG. 6.—Rate at which ear husks died on six corn hybrids planted at Columbus, Ohio, May 26, 1941.

10 strains. The slopes of the curves show that once started the ear husks turned straw color at about the same rate in all of the hybrids. Highly positive correlations were found between the percentages of dry ear husks and the percentages of dry matter in the grain ($r = +0.833$ with ± 0.190 significant at the 1% level, and $r = +0.868$ with ± 0.208 significant at the 1% level in the early and late plantings respectively in 1941). None of the strains studied had reached maximum grain development until at least 90% of the ear husks were dead in 1941.

In spite of the high correlation found between the percentage of dry ear husks and the dry matter in the grain, the number of dry ear husks was not a reliable index of relative maturities among strains of corn. For example, Iowa 939 which ranked no higher than fourth or fifth in dry matter in the grain, showed the highest number of dry ear husks throughout the period over which records were kept.

KERNEL DEVELOPMENT IN SHOCKED CORN

No record was found in the literature of investigations planned to determine whether translocation of materials into the grain continued after corn was cut and shocked. A survey in 1940 showed that a considerable number of fields were cut and shocked prior to maturity and it seemed desirable to investigate the possibility of continued grain development after shocking.

Data obtained from 26 small shocks which were cut before maturity and in which kernel weights were determined at the time of cutting and again after 8 days are given in Table 3. Increases, whether measured in grams or percentages, were highly variable. Samplings were not replicated. It seems significant, however, that every bundle indicated some grain development after cutting.

TABLE 3.—*Kernel weight increases after corn had been cut and shocked.*

Date of cutting	Dry matter in grain, %	Weight per 100 kernels, grams*	Increases after 8 days in shock†	
			Grams	%
		Iowa 939		
Aug. 16	42.5	17.2	(a) 3.3	19.2
			(b) 2.6	15.1
Aug. 20	45.9	19.5	(a) 3.6	18.5
			(b) 3.8	19.5
Aug. 25	55.2	24.3	(a) 1.5	6.2
			(b) 1.1	4.5
Aug. 29	60.4	25.6	(a) 1.7	6.6
			(b) 0.2	0.8
		(Ohio 26 × Ohio 51)		
Sept. 2	43.8	17.8	(a) 3.8	21.3
			(b) 4.1	23.0
Sept. 6	48.9	21.2	(a) 3.2	15.1
			(b) 1.2	5.7
Sept. 10	58.1	24.9	(a) 1.5	6.0
			(b) 1.3	12.0
Sept. 15	65.2	24.8	(a) 1.4	5.6
			(b) 1.6	6.4
		Ohio C 84		
Sept. 15	51.2	21.7	(a) 3.5	16.1
			(b) 1.3	6.0
Sept. 19	57.2	25.8	(a) 2.3	8.9
			(b) 2.7	10.5
Sept. 23	60.1	25.4	(a) 1.7	6.7
			(b) 1.2	4.7
Sept. 27	61.0	27.1	(a) 0.6	2.2
			(b) 1.4	4.9
Oct. 1	64.8	27.6	(a) 0.6	2.2
			(b) 0.5	1.8

*Ears sampled at time of cutting.
†Same ears as those used to determine weight of 100 kernels (a) sampled again after being in the shock 8 days; (b) ears from duplicate bundle sampled only after 8 days in the shock.

There are two important possibilities of error in the sampling and drying technics. First, during the drying process and because of the higher moisture content, a greater carmelization of sugars might occur in the samples obtained at the time of cutting than in those taken from the same ears 8 days later. This possibility was eliminated when seven sub-samples from a large lot of grain at a high moisture level were dried at different rates, with and without preliminary slow drying periods, and the final weights were found to vary only 0.5%.

Second, it is probable that part of the apparent increases can be attributed to the breaking of kernels in removing those samples taken at the time of cutting, due again to higher moisture than after drying in the shock for 8 days. Careful examination of the kernels in the dried samples, however, did not reveal differential breakage.

It should not be inferred that these data are presented as conclusive evidence that the grain continues to increase in weight after the plants are cut prematurely and shocked at once. The scope of the investigation was too narrow to justify definite conclusions, and the data are presented only because they offer interesting possibilities for future work to obtain a clearer picture of the conditions under which continued grain development may occur.

If such a study is initiated, it should include measurements not only of the changes in the grain, but also the change in the cob and in the remainder of the plant. Chemical analysis of the grain, cob, and plant would be desirable.

STAGES OF MATURITY AT WHICH CORN IS CUT AND SHOCKED IN OHIO

This phase of the investigation was based upon a survey covering 58 partially cut fields of corn in 19 Ohio counties in 1940 and 1941. Table 4 contains the data. About 30% of the fields in 1940 and 45% in 1941 were partially cut when the survey was made.

TABLE 4.—*Dry matter in the grain of corn when fields were being cut in Ohio, 1940 and 1941.*

Dry matter in the grain, %	Number of fields sampled			Part of maximum yield attained, %*
	1940	1941	Total	
45.1–50.0	1	2	3	63–73
50.1–55.0	10	5	15	73–83
55.1–60.0	12	11	23	83–91
60.1–65.0	2	13	15	91–98
65.1–70.0	0	2	2	98–100
Total	25	33	58	

*Percentage values are from Fig. 4 and are not corrected for increases that may have occurred in the shock.

Harvesting began prior to the time of maximum grain yields in most fields which were cut and shocked. Yield losses, however, cannot be accurately predicted from the grain development curve (Fig. 4)

since the shocking study showed that some grain development probably occurs after cutting.

Some factors which, from the farmer's standpoint, partially offset the yield losses from premature harvesting are (a) available labor is distributed over a longer period of time by starting early, (b) fewer leaves are lost giving a more desirable fodder to feed, and (c) early harvesting permits a more timely preparation of a seedbed for wheat.

It was generally evident from conversations with farmers that they did not know when corn was mature, nor did they realize that substantial yield losses result from premature cutting. Many fields could profitably have been harvested from a week to 10 days later than they were in 1940 and 1941.

SUMMARY AND CONCLUSIONS

Percentages of dry matter in the grain and kernel weights were measured at 4-day intervals in several corn hybrids during the latter part of their development periods in 1939, 1940, and 1941. The appearances of the ears and ear husks were noted at the time of the later harvests.

In order to determine whether the kernels continued to increase after being cut and shocked, 26 bundles were cut prematurely and the kernel weights were measured before and after drying in the shocks for 8 days.

Partially cut fields of corn were sampled in 1940 and 1941 to determine the stages of development at which corn is generally cut and shocked in Ohio.

The following conclusions are based on the data presented:

1. Corn is not mature until it has reached the maximum dry weight of grain which occurs at about 65% dry matter. Within individual ears maturity is reached at a slightly earlier point.

2. Percentage of dry matter in the grain is the best single criterion of relative and actual maturities in corn within the dry matter range covered by this investigation (30 to 80%). The number of days to mid-silking is the second best criterion, although it was found to be misleading in specific comparisons. A combination of these two criteria, with greater emphasis on the dry matter in the grain probably is most desirable for corn investigators.

3. The time at which the maximum weight per 100 kernels has been reached is not a practicable measure of relative maturity among strains since it involves a series of measurements, and also the end-point in kernel development is difficult to establish from the curves.

4. Ear appearance is the best practical guide for farmers to cut and shock corn unless moisture testing equipment is readily available. Maximum grain yields are attained when one-third to one-half of the ears are in the ripe stage and the remainder are in the hard dough stage.

5. Plant appearance is not a reliable index of relative or actual maturity.

6. Appreciable development of grain apparently occurs after immature plants are cut and shocked. Additional research is needed to verify this conclusion.

7. Harvesting is started before maximum possible yields of grain are attained in more than 50% of the fields that are cut and shocked in the areas surveyed. Harvesting may profitably be delayed for at least a week in many Ohio fields.

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DELAYED GERMINATION OR SEED DORMANCY IN VICLAND OATS[1]

ALVIN SCHWENDIMAN AND H. L. SHANDS[2]

IN the fall of 1940 several instances of delayed germination were noted in freshly harvested samples of Vicland oats, a new variety recently described by Stanton (10).[3] Certain samples when tested at room temperature germinated only 65% in two weeks. However, germination was increased to 95% or better when the seed was prechilled. As this variety was about to be released for commercial production,[4] it seemed important to determine the extent and nature of the delayed germination. The immediate need for such a study was occasioned by the necessity of establishing a satisfactory testing procedure for making germination tests in order to judge freshly harvested seed as to requirements for certification.

The main aspects of the physiology of delayed germination in small grains have been reported in the work of Harrington (5) and Johnson (6). Harrington was able to increase the germination of wheat, oats, and barley by artificial drying, opening the coat structures over the embryo with incidental wounding of the scutellum, cutting off the distal end of the caryopsis, removal of the lemma and palea from oats and barley, weakening of the coat structures over the embryo of wheat by the use of sulfuric acid, increasing the oxygen pressure in the atmosphere, and germination at 12° to 16°C.

Johnson (6) was also able to show an increase in the germination of *Avena fatua* by the use of an increased oxygen pressure, lowered germinating temperatures, and by the use of potassium nitrate. Both of these workers are in agreement in stating that the dormant condition is imposed by coat structures impermeable to oxygen.

Johnson (6) considered that the after-ripening process may consist of a series of changes in the tissues of the seed coat which results in an increased permeability to oxygen. Harrington (5) also stated that the improved germination of nonafter-ripened cereals brought about by various treatments appears to result from increasing the permeability of coat structures to oxygen.

Toole (11) and Whitcomb (12) were primarily responsible for the development of the prechilling method for improving the germination of freshly harvested cereals.

Lewis (9) explained the response to low temperatures by nonafter-ripened seed to be most likely a matter of reducing the speed of all processes in germination to that of a limiting factor.

Other phases of the problem of delayed germination in cereals have been dealt with in the literature as indicated by the following conclusions reported in various papers: Cutting immature grain increases the amount of delayed germination (8, 12); low storage temperatures prolong the after-ripening process (6, 8); more delayed germination occurs after cool, wet harvest years (3, 9); more delayed

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[3]Figures in parenthesis refer to "Literature Cited", p. 687.

[4]First released in 1941.

germination is found in the kernels from the basal whorls of *Avena fatua* than from the upper whorls (6); more delayed germination occurs in secondary than in primary seeds (1, 6); all degrees of prompt, slow, and delayed germination are found in varieties of *Avena sativa* (1); delayed germination in *Avena* is inherited as a recessive character (4, 7).

EXPERIMENTAL METHODS

Unless otherwise indicated, all tests were made by placing two replicates of 100 seeds each between standard germination blotters and reading the test at the end of 14 days. Control or "check" germination tests were made at approximately 22°C. Prechilled tests were made by holding moistened seed at 4°C for 4 days and then placing the seed at 22°C for germination to be completed. The effectiveness of any treatment in breaking the delayed germination is indicated by the increased germination obtained over and above the percentage germination of the control at 22°C. The facilities of the Wisconsin State Seed Laboratory were used in making most tests. Only limited preliminary tests were made in the fall of 1940. All other tests were made with seed of the 1941 and 1942 crops.

RESULTS

EFFECTS OF VARIOUS TEMPERATURES AND REMOVAL OF HULLS

Table 1 shows the effects of various temperatures and of the removal of the hulls upon the percentage germination. In this test all

TABLE 1.—*Effect of temperature and of the removal of hulls upon the percentage germination of Vicland oats, all tests started August 19, 1941.*

Sample No. and Wis. county source	Hulls	Percentage germination after						
		6 days		14 days				
		16°C	22°C	4°C*	8°C	12°C	16°C	22°C
3-Iowa	On	95	83	100	97	98	97	96
	Off	97	93	77	81	100	98	98
9-Dane	On	71	17	94	93	93	74	43
	Off	94	51	99	98	98	98	83
11-Columbia	On	82	43	90	93	93	84	69
	Off	97	85	98	99	97	99	95
13-Columbia	On	83	23	92	90	91	86	63
	Off	97	82	98	98	98	99	95
14-Sauk	On	97	71	98	97	97	98	95
	Off	97	97	99	98	97	98	99
15-Outagamie	On	91	58	99	96	98	92	90
	Off	94	93	96	98	97	96	98
18-Walworth	On	82	33	95	96	96	89	47
	Off	95	71	97	91	97	96	93

*Seeds prechilled for 4 days at 4° C and then placed at 22° C to germinate. All other seeds held constantly at the temperatures indicated.

seeds were rolled in moistened paper towels which were placed in covered enamel trays kept in thermostatically regulated germination chambers. In most cases removal of the hulls increased the rapidity and the percentage of germination. Although removing the hulls gave a fairly satisfactory test after 14 days at all temperatures, this method is laborious. Germination at continuous low temperatures between 8° and 12° C appears to give very satisfactory results without removing the hulls, if a 14-day interval is used. The objections to this method would be the longer time interval required and the need for a continuous low temperature germinating chamber.

Although not indicated in Table 1, the prechilling method allows for complete germination after 8 to 10 days. This method is not only rapid but requires a smaller amount of refrigeration space. If space is very limited, seed to be tested may be placed between moistened filter papers in petri dishes. Best results are secured if the seed is allowed to take up a moderate amount of moisture before the chilling is started. If seeds are either completely dry or excessively wet when chilled, poorer germination may result.

SEASONAL DURATION OF DELAYED GERMINATION

Fig. 1 shows the seasonal duration of delayed germination in Vicland oats. The reason for the drop in germination of the nonprechilled seeds on December 15, 1941, and January 14, 1942, is not clear, but it appears to have been a real one as it occurred in all nonprechilled replicates. Since the seeds for all germination tests were counted out from bulk lots at the beginning of the experiment and placed under natural storage conditions, progressive selection of the seed could not have been responsible. Since the authors have been able to induce delayed germination in Vicland oats by dry chilling in a refrigerator it is possible that the lower outdoor temperatures during December and January may have been responsible.

In this same study on the seasonal duration of germination, 12 replicates of the same oat sample were planted in soil. Both primary and secondary seeds planted in the soil germinated as well as the seed which had been prechilled. The soil agent responsible for overcoming delayed germination is not known, but it may be soil nitrates as indicated later.

DELAYED GERMINATION IN RELATION TO PANICLE POSITION

Table 2 shows that in Vicland oats there is more delayed germination in the secondary seeds borne on the basal panicle whorls than in the secondary seeds of the upper whorls. This relationship does not hold for the primary seeds. While State's Pride oats shows a marked effect of the date of harvest upon the amount of delayed germination in the secondary seeds, this is not true for Vicland. This same test was repeated in the fall of 1942 using both Vicland and State's Pride oats harvested on July 8, July 17, and July 22, but germination was immediate for all kernels of both varieties.

Though these results when taken alone are not conclusive, they are in agreement with Johnson's (6) findings that *Avena fatua* seeds hav-

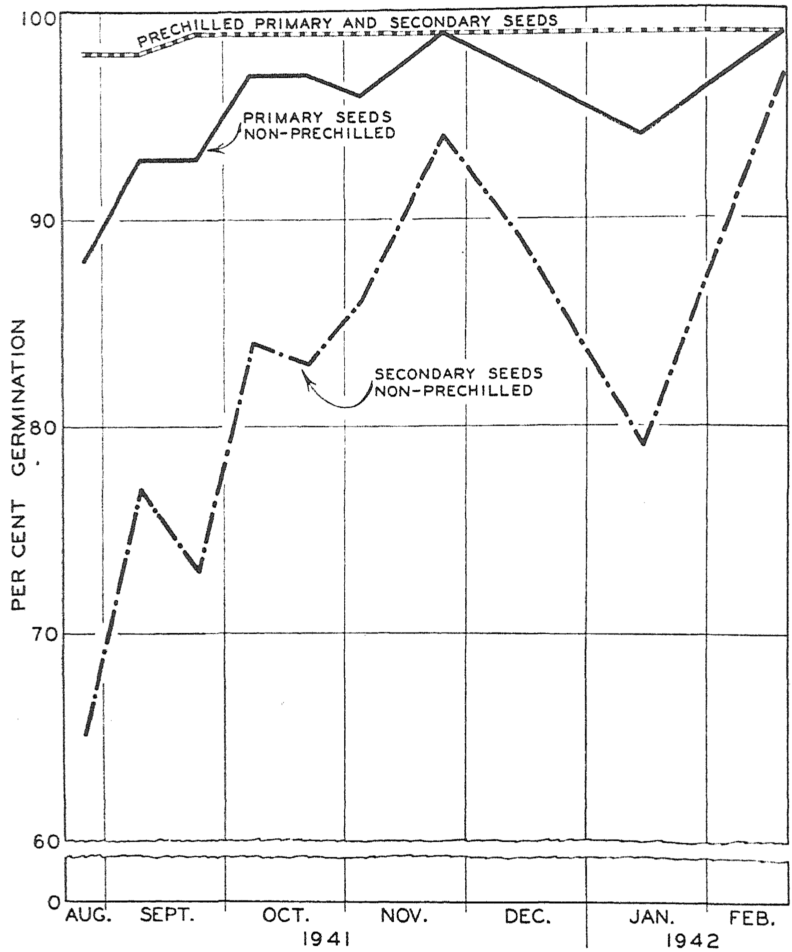

FIG. 1.—Extent and duration of delayed germination in Vicland oats as shown by the germination of prechilled and nonprechilled seeds. The percentages of germination for prechilling are the averages of 12 replicates of 100 seeds each; for the nonprechilled seeds, the averages of 6 replicates of 100 seeds each.

ing a basal panicle position exhibit more delayed germination than seeds having a terminal position. More delayed germination in prematurely cut oats is also in agreement with the work of Whitcomb (12) and Larson, *et al.* (8).

EFFECT OF CHEMICAL TREATMENTS

Table 3 shows the effect of various chemicals upon the germination of a sample of oats exhibiting delayed germination. All nitrates, whether used for presoaking the seeds or for moistening blotters, were effective in increasing the germination. The use of ammonium nitrate,

TABLE 2.—*Delayed germination in relation to panicle position and date of harvest for Vicland and State's Pride Oats, test started Sept. 4, 1941, and read Sept. 18.*

Treatment	Panicle whorls	Percentage germination			
		July 15 harvest		July 21 harvest	
		Primary	Secondary	Primary	Secondary
		Vicland			
22°C	Upper	100	94	99	89
	Central	100	80	99	83
	Basal	99	82	98	79
Prechilled	Upper	100	100	100	100
	Central	100	100	99	100
	Basal	98	99	100	98
Soil test	Upper	98	95	98	98
	Central	96	100	98	96
	Basal	94	93	89	93
		State's Pride			
22°C	Entire panicle	95	40	100	91
Prechilled	Entire panicle	100	99	100	100
Soil test	Entire panicle	95	96	93	97

although giving a high germination, definitely retards the elongation of the roots and the first internode and coleoptile for the first 8 to 10 days. Subsequent tests using the same concentration of the chloride salts of calcium, potassium, and ammonium, indicate that the germination increase is attributable to the nitrate and not to a simple salt effect.

TABLE 3.—*Effects of various chemicals upon the germination of secondary seeds of Vicland oats, two replicates of 50 seeds each placed between blotters at 22°C, all tests started Sept. 8, 1942.*

Treatments	Percentage of seeds with coleoptiles seed length or longer		
	4 days	8 days	14 days
Blotters moistened with water	50	82	86
Blotters moistened with a 0.2% solution of KNO_3	65	98	100
Seeds soaked 1 hour in a 2% solution of KNO_3	76	96	97
Blotters moistened with a 0.2% solution of $Ca(NO_3)_2$	54	100	100
Seeds soaked 1 hour in a 2% solution of $Ca(NO_3)_2$	86	98	100
Blotters moistened with a 0.2% solution of NH_4NO_3	73	99	98
Seeds soaked 1 hour in 2% solution of NH_4NO_3	85	98	100

A comparison was made of the effects of prechilling and using a 0.2% potassium nitrate solution to moisten the germination blotters. From Table 4 it appears that the use of nitrates was equally as effective in overcoming delayed germination as was prechilling. Ordinarily, when seed is prechilled for 4 days, a total of about 10 days is required before germination can be read. However, when potassium nitrate is used the test can be read after 6 to 8 days. The low germination for sample No. 2 is an example of cases which occasionally occur following prechilling. In no case has a lowered germination resulted from the use of dilute potassium nitrate.

TABLE 4.—*A comparison of the effects of normal laboratory germination, prechilling, and the use of a 0.2% solution of potassium nitrate upon the germination of samples of Vicland oats showing marked dormancy.*

Sample No.	Date of test	Percentage germination after 14 days		
		Blotters moistened with water	Seed prechilled	Blotters moistened with KNO_3
92	Nov. 10, 1941	68	88	99
94	Nov. 16, 1941	80	98	98
149	Nov. 31, 1941	58	87	86
186	Dec. 11, 1941	79	91	99
191	Dec. 14, 1941	80	99	99
195	Dec. 15, 1941	72	98	97
196	Nov. 15, 1941	83	96	99
197	Nov. 15, 1941	72	99	97
206	Nov. 18, 1941	70	95	95
207	Nov. 19, 1941	60	97	95
1	Aug. 18, 1942	51	87	98
2	Aug. 18, 1942	45	39	99
3	Aug. 18, 1942	61	99	96

DISCUSSION

The results obtained from these tests demonstrate that delayed germination in Vicland oats is a laboratory problem and not one affecting germination in the field. From the practical viewpoint delayed germination may prove very desirable in wet harvest seasons in preventing sprouting in the shock. Deming and Robertson (2) found considerable delayed germination in Kanota oats (*Avena byzantina*) in the laboratory and also observed that this variety sprouted less in the shock than did other varieties without delayed germination. During the wet harvest season of 1942 there were some observations of less sprouting in Vicland oats than in other varieties.

The results presented in this paper suggest no basis for explaining the wide variations which occur in the degree of delayed germination found in various samples of Vicland oats. Although immaturely harvested oats may exhibit more dormancy in some varieties, this does not seem to have been the case with Vicland in 1941 or 1942. Very little information is available to show how local environmental conditions may influence the development of the delayed germination characteristic.

With one exception (6) there have been no previous reports of the possibility of using nitrates in place of prechilling to overcome delayed germination in oats or other grains. This substitution of methods appears entirely feasible, but further observations will be desirable before any conclusive statement can be made. Johnson (6) has suggested that the stimulation by potassium nitrate might be considered to result from a direct germinative stimulation by the absorbed anion, from indirect effects of the absorbed anion such as, for example, increased utilization of stored carbohydrates, or from chemical effects upon the seed coat which produce increased permeability to oxygen.

SUMMARY

Laboratory and soil germination tests were made to determine the extent and nature of delayed germination in Vicland oats. Many samples when tested under normal germination procedures in August and September gave only 40 to 60% germination after two weeks.

Removing the hulls greatly increased the rate and the total percentage germination. Germination at continuous low temperatures between 8° and 12° C gave satisfactory tests after 10 to 14 days without removing the hulls. A rapid and satisfactory test was secured by prechilling the moistened seed for 4 days at 4° C and then placing it at 22° C for 6 days.

Tests made at intervals of two weeks to a month between August 1941 and February 1942 indicate that delayed germination in Vicland oats under natural storage conditions is overcome by February of the year following harvest.

Secondary seeds showed more delayed germination than primary seeds. Some evidence was found to indicate that seeds having a basal position in the panicle show more dormancy than oats in terminal positions. No definite relationship was noted between stage of maturity at harvest and degree of dormancy.

The use of a 0.2% solution of potassium nitrate for moistening the germination blotters appeared to be equally as effective as prechilling in overcoming delayed germination.

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INSECT RESISTANCE IN CORN[1]

JOHN H. BIGGER[2]

THE gradual changes of agricultural practices which have been made by American farmers during the past three-quarters of a century have greatly altered insect control programs necessary to the economical production of corn in the Corn Belt area. The entire ecological picture has been changed. The environment to which the insect is exposed today is quite different from that existent during the middle of the last century. Much of the change has taken place during our lifetime, yet this is a fundamental concept which has not received the attention to which it is entitled.

Most of the insects with which we are now concerned were present prior to the start of agricultural development in the midwest. They were, however, generally restrained by their environment and natural enemies. When the original prairie sod was broken for the planting of corn, the soil was in a highly fertile condition, and the resulting crops grew rapidly and strongly. The resultant of these two conditions was a minimum of loss resulting from insect damage.

Repeated growth of corn or the use of corn-oats or corn-oats-timothy rotations produced an entirely new set of conditions at the close of the last century and the early years of the present century. Insects which are natural feeders on the *Graminae* had taken full advantage of the increase in the presence of the full-season and continuous feeding areas that were an integral part of the new agricultural program. Natural enemies, such as birds, skunks, and snakes, had been reduced in numbers. Soil fertility had suffered. The net result was a rather rapid build-up of such insects as white grubs, *Phyllophaga* spp., wireworms, Elateridae, the corn rootworm, *Diabrotica longicornis* Say., corn root aphids, *Anuraphis maidiradicis* Forbes, and chinch bugs, *Blissus leucopterus* Say., and severe crop losses due to attacks by these insects. The grape colaspis, *Colaspis brunnea* Fab., also appeared sporadically during this period.

About the time that this situation became really serious, legumes were rather generally introduced into rotations. Farmers began to use red clover and later sweet clover more intensively and with a purpose. In fact, two purposes were served, *viz.*, the change served at least partially to recoup the losses in soil organic matter and fertility and it served to break up the continuous grass sequence. The entomological picture was entirely altered. Here was a new ecological situation. This change served to reduce, at least partially, losses from the grass-feeding insects. By the third decade of the present century these insects were considered to be at least partially controllable by rotation with clovers. However, the general trend of fertility downward was not entirely checked, even by the introduction

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of sweet clover, so that the corn plants were less able to withstand insect feeding and the problem of control became increasingly difficult. Changes in certain tillage practices have been introduced, but have failed to change the trend.

Other changes of wide significance have occurred in the insect picture. During recent years we find such insects as the southern corn rootworm, *Diabrotica duodecimpunctata* F., which is more or less a general feeder, playing an increasingly important role. These insects are not amenable to control by rotation and not readily or completely controlled by tillage practices. The grape colaspis has reappeared as a perennial problem on corn and soybeans. The soybean has become one of its principal food plants and the immense increase in soybean acreage may be the reason for this situation. It is only partially controlled by rotation or tillage practices.

Two other common insects that have greatly affected our Corn Belt economy are grasshoppers (Locustidae) and the corn earworm, *Heliothis armigera Hbn.*, neither of which is materially affected by cultural practices commonly followed in the great corn-growing area of the country.

None of the insects so far brought into the picture is new to our agriculture. They have simply taken advantage of changes in cultural practices which reacted in their favor. But in the meantime new insects have been introduced and become firmly established in the Corn Belt. Of these the one which commands our immediate attention is the European corn borer, *Pyrausta nubilalis* Hbn. This insect is somewhat, but not completely controllable by cultural or tillage practices that are economically possible. The Japanese beetle, *Popillia japonica* Newm., is a present threat, but still to be dealt with.

In the meantime another factor, not yet considered in the development of our corn economy, is the appearance and widespread adoption of control-pollinated or hybrid corn. This has had a material effect upon the insect picture. The genetic complex of the corn plant has been sorted into various combinations different from those of the original plant from which the inbred lines bearing these various combinations of genes was produced. There have been developed large numbers of inbred lines among which there is, at least in some cases, a greater range of susceptibility or resistance to insect attack by certain insects than was present in the original parent material. It has been suggested that this is the direct cause of the apparent increase in damage by the corn leaf aphid, *Aphis maidis* Fitch, during the past 5 to 8 years.

From the foregoing it might appear that the control of insects attacking corn has arrived at an impasse. It is not intended that such a conclusion be arrived at, but rather to point out that changing conditions have altered the corn-insect picture to the extent that practices which have in the past given entirely satisfactory insect control are not now entirely effective. This in itself would serve to indicate the necessity for a different and newer attack on the problem, which brings us to the point of the present dissertation, the use of insect resistant strains, varieties, or hybrids of corn for corn crop production.

The use of insect-resistant or tolerant strains is not new. This biological approach to the insect control problem in the development of efficient agricultural production has been known and advocated since Havens (6),[3] in 1792, published an item regarding the Hessian fly resistance of the Underhill variety of wheat. However, the possibility of the use of this agency in preventing damage to corn did not come to the fore until 1917, when certain open-pollinated varieties of corn were found to be resistant to, or tolerant of, the attack of the second brood of chinch bugs (5).

Soon after that came the development of the use of inbred lines of corn to produce commercially available hybrids satisfactory for the farmer to use. This put a new tool into the hands of investigators searching for some way to defeat the ever-increasing inroads of insects upon the corn crop.

The wide range in the genetic complex of inbred lines of corn was known. It was also recognized that they varied widely in their resistance or susceptibility to plant diseases. It was soon found that they also varied in their relative susceptibility or resistance to insect attack.

This knowledge was first put to use in the attack on the European corn borer problem. As early as 1924 tests of varieties had shown marked variation in the borer population between varieties of the same maturity and height grown in closely adjacent plots in Ohio (10). In 1927 tests of 252 crosses between inbred lines were carried out. Since then, wide-scale tests of inbred lines of corn have been made in Ohio, Indiana, Michigan, and, in 1942, in Illinois, by various state and federal workers in closely cooperative programs between entomologists and plant breeders. As a result, there can no longer be any doubt that there exists germ plasm which possesses the quality of resistance to European corn borer, in the area where a single brood predominates, that it is present in some of our inbred corn lines, and that it is transmitted to the progeny of such lines. This resistance has been ascribed to simple Mendelian dominant factors by some, but the most recent and complete report by Patch (12) states that, "The cumulative effect of an undetermined number of mutiple factors in inbred lines in producing borer resistance in hybrids is clearly indicated." We have seen further evidence in Illinois in 1942 which tends to corroborate the statement by Patch. This information has become widely known and has been applied in production programs in areas where the insect is an economic factor in corn production.

Shortly after this work was started it was possible to make satisfactory tests of the relative reactions of inbred lines to the attack of second brood chinch bugs. This work started in the early 1930's in the breeding plots of J. R. Holbert at Bloomington, Ill. (8, 9). The work of Holbert in Illinois in cooperation with the Illinois entomologists and that of Snelling and Dahms (13) in Oklahoma and of Painter and Brunson (11) in Kansas showed that inbred lines of corn existed at that time which transmitted to their progeny a high degree of resistance to second brood chinch bugs, and it was indicated (8)

[3]Figures in parenthesis refer to "Literature Cited", p. 693.

that ". . . . . some inbred lines carry dominant factors for chinch bug resistance, while other inbred lines carry dominant factors for susceptibility." Since that time standard inbred lines have been pretty well catalogued and new inbred lines developed which have been shown to carry chinch bug resistance factors and to transmit them to their progeny. This information has been put to practical use by seedsmen who are producing hybrids for the use of farmers in the chinch bug infested areas.

In the meantime, work has progressed toward studies of the relative resistance or susceptibility of inbred lines of corn to various other insects. Among these the corn leaf aphid holds a prominent place. Since 1937, the relative abundance on, and damage to, inbred lines by this insect has been studied intensively in Ohio, Indiana, Wisconsin, and Illinois. It has been shown (14) that great variations exist in the resistance and susceptibility of inbred lines of corn to the corn leaf aphid. Further, it has been shown that the aphid reactions of many of the lines are transmitted to their single crosses. This information is known to seedsmen and is being put to practical use.

Progress has also been made in determining the relative resistance or susceptibility of inbred lines of corn to attack of the corn earworm. An intensive study of this problem has been in progress since the assignment of R. A. Blanchard to it in 1937. Inbred lines and their crosses have been studied in an area extending over the central and southern states. The studies show (3) that, "Some inbred lines tend to be consistently resistant, whereas others are definitely susceptible," and further that ". . . . resistance to the corn earworm is inherited." It is also shown that "Some inbred lines transmitted a high degree of resistance even when combined in single crosses with susceptible lines," and that "Some inbred lines were stable in their resistance or susceptibility at the different localities included in this study." Progress is being made in the development of new inbred lines carrying germ plasm which is highly resistant to the corn earworm.

The southern corn rootworm has also received considerable study (1) at various stations in the Corn Belt since 1937. The most comprehensive work that has been reported was carried on in Illinois since R. O. Snelling has been stationed there for the purpose of resistance studies. More than 60 inbred lines with yellow endosperm and about 30 lines with white endosperm were studied as lines and in single crosses. The results of this study have been reported (2) and showed a marked differential in response of the plants to attack by the larvae of this insect. One inbred line was outstanding in its resistance to lodging following the attack. This resistance is shown to be heritable. There is unreported work at the Illinois Experiment Station which indicates a definite morphological effect upon the larvae of this insect when they feed upon selected inbred lines of corn.

Grasshoppers have received their share of study, especially in Kansas. Brunson and Painter (4) studied the comparative damage to corn strains during the 1936 outbreak in Kansas. They report that, ". . . . outstanding instances of differential injury among corn varieties, top crosses, and hybrids were noted." They state also that, "As a rule, the varieties and inbred lines of corn showing the greatest

resistance originated in areas where grasshoppers are a natural environment," which is a definitely significant statement and worthy of attention from other workers. Greenhouse studies carried on at Illinois during the period 1938–40, and not yet published, show that hoppers of the species *Melanoplus differentialis* (Thos.) show distinct preference for certain inbred lines when given choice, and further, that feeding of the hoppers on different lines has a definite effect upon the development of these hoppers throughout their life.

In 1941, Hoegemeyer (7) had an opportunity to make some observations relative to white grub resistance in Kansas. He found that single-cross and double-cross combinations of corn differed significantly in the percentage of plants root lodged and that these differences seemed to be a manifestation of differences in root injury by these insects. He states that, "The single crosses having the least root injury when combined gave the double cross combinations which were least injured, whereas, the more severely damaged single crosses in combination gave double crosses which were more severely damaged by white grubs."

Some studies have been made concerning the resistance of inbred lines to stored grain insects. These have not been published but indicate the possibility of the use of this characteristic in the production of commercial corn hybrids.

There may be work in progress with other insects which has not come to the writer's attention, or has not been published. The foregoing is a brief summary of major accomplishments to date. The job is far from complete. Certain insects, such as the grape colaspis and the seed corn maggot, *Hylemyia cilicrura* Rond., have not been studied. The European corn borer must be restudied with reference to resistance to the two-brooded area. Wireworms have not been touched. Neither has this problem been thoroughly studied with reference to the morphology and physiology of the plant in its relation to the resistance of the plant. The effect of feeding on the various lines upon the morphology and physiology of the insect has only been touched. The work done has all been elementary and a big job is still ahead in which it is essential that entomologists, plant breeders, agronomists, physiologists, chemists, and possibly other specialists must cooperate before the problem of the plant-insect relation can be fully understood.

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INSECT RESISTANCE IN WHEAT[1]

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AMONG the methods of preventing losses caused by the insect pests of growing wheat, the breeding of insect-resistant varieties now appears to be one of the most promising, and the following discussion relates largely to methods that have been or are being used to produce varieties resistant to the hessian fly, *Phytophaga destructor* (Say).

REVIEW OF LITERATURE

The earliest recorded observation of hessian fly resistance in wheat was made by Isaac Underhill near Flushing, Long Island, in 1782 (1, 8, 12).[3] This resistant wheat was described as a hard-stemmed, yellow-bearded variety, which was subsequently given the name of Underhill. Packard (21) stated that, "Of the different varieties of fly-proof wheat, the Underhill variety has for nearly a century been highly recommended."

Chapman (8), in 1778, besides recommending a resistant variety of wheat, advocated late sowing as a precaution against fall fly attack and the planting of varieties of quick, vigorous growth against spring attack. This is perhaps the first observation on the desirability of delayed seeding, the most practical method of general fall fly control in use today. Delayed seeding, however, is ineffective under some adverse seasonal conditions and involves a disadvantageous agronomic practice. There is no known control of the spring brood of flies except the use of resistant varieties.

In the earliest references to "fly-proof" wheat, Underhill, Lancaster, Lawler, and White Flint are mentioned frequently. In later accounts, China, Clawson, Mediterranean, Red Chaff, Red May, and Fultz occur often.

Woodworth (37) is credited with making the first systematic study of the variations in fly resistance. He examined 125 varieties of wheat being grown at Berkeley by the California Agricultural Experiment Station, classified them into three groups according to degree of resistance or susceptibility, and also called attention to the fly resistance of durum wheat. Roberts, *et al.* (30) and Gossard and Houser (13), in resistance tests in New York and Ohio, found that vigorous-growing, strong-strawed varieties were less liable to injury by the fly than slow-growing, weak-strawed varieties and found little evidence to support the idea of immune varieties. Dawson was found resistant in many counties of New York, and susceptible in Canada and Ohio.

In the years following, many papers on fly-resistance studies appeared, notable

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[3]Figures in parenthesis refer to "Literature Cited", p. 702.

among which are those by McColloch and Salmon (19), Haseman and McLane (15), Packard (22), and Painter, *et al.* (26). McColloch's early work in particular stimulated new interest in breeding fly-resistant wheat. The wide extent of researches on the hessian fly is emphasized by the fact that Wade (34) published a bibliography of 1,256 titles on the fly, including many on the subject of resistance. In 1941 Snelling (32), Packard (23), Platt and Farstad (29) published papers containing extensive reviews of fly and wheat-insect resistance.

Many of the papers that appeared during the period from 1891 to 1931 tend to confirm the observations of earlier workers that fly immunity in the ordinary varieties of winter wheats does not exist, although such varieties as Dawson, Honor, Illini Chief, Fulhard, Michigan Wonder, Red Rock, and others may possess a high degree of resistance in some environments; and that such characters as vigor of growth, stiff, hard straw, earliness, and tight sheaths may be important factors in reducing fly damage.

Painter, in 1932, isolated a resistant strain of Marquillo and successfully transferred fly resistance from this spring wheat to five varieties of common winter wheat (25). The resistance derived from Marquillo appeared to be recessive and due to more than one genetic factor. Though showing only mild resistance under epidemic conditions of infestation in Indiana and in some eastern states, selected hybrids under similar conditions of infestation in tests in Kansas and Missouri were much more resistant than common winter wheats.

Caldwell and Compton (5) found Illinois No. 1 W38 in 1935 to be more highly resistant than Marquillo in Indiana, and durum wheat F. P. I. 94587 to approach immunity to infestation. These varieties and a few selected hybrids with common winter wheats have been tested in cooperative uniform nurseries over a period of years in a number of widely separated states and have been found to develop little or no infestation.

Cartwright and Wiebe (7) crossed Dawson C. I. 3342, found to be resistant to the fly in California, with two susceptible wheats, Big Club C. I. 11761 and Poso C. I. 8891. From a study of the classification of the F_2 lines based on the infestation behavior in F_3 rows, a ratio of 15 resistant to 1 susceptible was obtained. It was concluded that in these crosses, under the conditions of the experiments, the resistance of Dawson was controlled by two genetic factors. Thus, for the first time, the inheritance of resistance was established on a factorial basis.

Noble, *et al.* (20) found that infestations of F_2 populations of crosses Dawson ×Illinois No. 1 W38 and Dawson×Illinois No. 1×(Norka×Carina) averaged higher than had Dawson×Poso F_2 in previous studies. The data indicated that for fly resistance Illinois No. 1 W38 and Illinois No. 1×(Norka×Carina) were better than Dawson by at least one factor.

SOURCES OF FLY RESISTANCE

With the exception of Dawson, Kawvale, and a few other varieties and strains locally resistant to the fly in some sections, commercially grown common winter wheats, because of their variable reaction to infestation, appear to have only incidental value as fly-resistant parentals. All available American winter wheats have been tested for fly resistance at several points in the central wheat-producing states by federal entomologists and all have been found susceptible in one or more tests. Selections from several white winter wheats from Turkey have recently been made in Indiana by W. B. Cartwright. So

far these selections from the Turkish varieties have shown a high degree of resistance in tests against heavy fly infestations.

In the cooperative fly-resistance work of the Bureaus of Entomology and Plant Quarantine and Plant Industry of the U. S. Dept. of Agriculture and the Departments of Entomology, Botany, and Agronomy of the California, Kansas, Indiana, and Pennsylvania Agricultural Experiment Stations, most available foreign plant introductions, principally spring wheats, have been tested for fly reaction under conditions of heavy infestation in the greenhouse and in widely distributed outdoor test plots. The records are unpublished, but they show that over 25 of these foreign varieties and strains of spring wheat have a degree of fly resistance approaching or exceeding the American spring wheats, Marquillo, Illinois No. 1 W38, Java C. I. 10051, Dixon C. I. 6849, and Marvel C. I. 8876. Others, reported by Bayles and Taylor (3) and by Cartwright, *et al.* (6), show promise of producing highly resistant lines if reselected. With the exception of Dawson and Kawvale, all the resistant varieties yet found possess too many undesirable characteristics to be of use except for transmitting fly resistance when crossed with adapted varieties.

Analysis of the resistance reaction of many selections and crosses indicate that the many resistant strains now available appear to fall into about five levels of fly resistance, namely, (a) the limited general resistance of Dawson and Kawvale, except that in California Dawson is more resistant than Illinois No. 1 W38 and that in parts of Kansas Kawvale is highly resistant; (b) the medium resistance of Marquillo; (c) the high resistance of Illinois No. 1 W38, Java, Uruguay selections, and Marvel spring wheats; (d) the apparently somewhat higher resistance of certain white winter wheat selections from Turkey when tested in Indiana and Dawson in California; and (e) the near immunity found in P. I. 94587 durum and perhaps other wheats of lower chromosome number.

In California Dawson has been successfully used as a source of superior resistance, but in the central and eastern states it has been necessary to resort to the spring wheats for sufficient resistance to insure adequate fly protection. Marquillo, which transmits effective resistance to the fly in Kansas and Missouri, exhibits lower resistance east of the Mississippi River, where the relatively higher resistance of Illinois No. 1 W38 is required. Winter selections from hybrids of Uruguay wheat selections, IVy (Gelou) C. I. 12001, IVCI + No. C. I. 12034, and Renacimiento, seem to be better adapted in Kansas and Missouri than those from hybrids of Illinois No. 1 W38. The durum P. I. 94587 gives some evidence of transmitting near immunity to the fly to its winter hybrids, but also produces sterility and poor types in many of them. A few of the better types have been selected. As in most species hybrids, backcrossing and reselection will be required to produce desirable fly-immune strains. Some of the winter hybrids with fly resistance transferred from spring wheats may lack superior winter hardiness, which is being added by further crossing and selection. The white, winter selections from Turkey with high fly resistance have advantages over the spring wheats of winter habit and ability to tiller. Weak straw, disease susceptibility, low yield,

white grain, unknown milling quality, and lack of adaptation are undesirable characteristics of some of their hybrids which may be overcome by a backcross program.

Plant breeders, entomologists, and pathologists at several stations have successfully combined the various types of fly resistance with resistance to disease in good, adapted varieties of winter wheat. Some of these strains show promise of being equal or superior to many of the commonly grown susceptible varieties, even when these latter are not infested.

BREEDING NEW RESISTANT VARIETIES

Requirements for breeding fly-resistant wheat varieties vary with the area where they are to be grown. Different methods of breeding have been used partly because of differences in the philosophy of the breeder and partly because of differences in area, types of wheat, and races of the fly. In California, where comparatively few varieties are needed and standard types are generally acceptable, the backcross method described by Briggs (4) apparently is best suited for breeding fly- and disease-resistant varieties. Workers in California have successfully transferred commercially valuable fly resistance to two club wheats, Poso and Big Club.

The backcross breeding program to produce fly-resistant varieties of wheat for California was planned and undertaken by W. B. Cartwright and G. A. Wiebe. This program called for crossing Dawson to Poso and Big Club and making five successive backcrosses of fly-resistant segregating hybrids to the susceptible parent in order to recover Poso and Big Club agronomic types. From F_3 of the last backcrosses, lines homozygous for fly resistance and agronomic type are composited. Such breeding theoretically should result in new varieties having approximately 98.5% of the characteristics of the recurring parent.

In Kansas and Indiana and throughout the winter-wheat areas of the Middle West and East, where many varieties of hard and soft wheats are grown and the prevalent commercial types need to be improved in many ways, the breeding for fly and disease resistance is complicated. Many strains of wheat must be tested for fly and disease reaction in several environments. A large number of simple and complex crosses, some backcrosses, and a great amount of testing of pedigreed lines are used to combine in one variety resistance to different races of the fly—presumably only one race occurs in California—and fungous diseases with the ideal type of wheat for a given locality.

In Kansas workers of all agencies engaged in wheat improvement meet to formulate joint plans and to determine what crosses should be made and how, when, and where the progeny should be grown in the various test plots. This avoids duplication, allows full advantage to be taken of all materials, and results in the best possible combinations of desirable characteristics in a single hybrid with a minimum of wasted effort.

The continuous-selection-pedigree method is used for selecting resistant parentals and hybrids through F_6. Seed of F_2 to F_5 generations

is divided and planted in spaced rows in several nurseries, where the plants are subjected to different pests for the purpose of eliminating the undesirable strains. Strains susceptible to the hessian fly are dropped at harvest on the basis of their reaction to fall infestation. Selected rows are pulled, examined in the laboratory, and disposed of according to reaction to spring fly infestation. Selections are rotated, passing through a successive series of nurseries until all types of resistance are fixed and undesirable characteristics are eliminated.

During 8 years of cooperative work at the Kansas Agricultural Experiment Station approximately 10,000 strains, principally varietal and hybrid selections, including most known varieties and species of wheat, have been studied for fly reaction, at one time or another, in the experiment station fly-test nurseries and in one or more of the similar nurseries that have been conducted for various periods at Wichita, Manhattan, Parsons, Ramona, Bennington, and Junction City, Kans., and at Springfield, Mo. At present, nurseries are located at Manhattan and Bennington, Kans., and Springfield, Mo. The Bennington nursery is useful in studying the reaction of plants to the strain of flies prevalent in the area where hard wheat is grown. Plots have been sown at Springfield since 1912 for tests of wheats against the strain of flies prevalent in the soft-wheat area, with scarcely a break in high fly populations. Constant heavy infestations have made the Springfield records particularly valuable in interpretating infestation reactions in other test nurseries.

Several varieties possessing limited fly resistance have been released. Kawvale was approved in 1931 and released to growers in Kansas in 1932. Because of its resistance to the fly in the extreme western portion of the soft-wheat area, and to loose smut and rusts, it now leads all other wheat varieties in acreage in eastern Kansas. In 1941, partly on account of its Kawvale type of fly resistance and high yield, Pawnee (Kawvale×Tenmarq C. I. 11669) was approved for distribution in Nebraska and is being increased by the Kansas Station. Experimental plantings of Pawnee in the hard-wheat area have shown commercially valuable resistance to the fly.

Big Club 38, a fly-resistant strain developed by Noble and Suneson, was released experimentally in California in 1938 after the third backcross of Dawson×Big Club to Big Club. No damage to this variety has occurred in field test plots during the last 4 years, while nearby fields of ordinary Big Club were visibly damaged by infestations of the fly in from 50 to 98% of the plants. A new fly-resistant composite, Poso 41, involving Dawson×Poso, is being increased for release in California in 1942, and the final crosses involving Dawson×Big Club will be tested in 1943, when lines homozygous for resistance to the hessian fly, bunt, and stem rust will be selected for compositing and release.

During the last 15 years there has been a steady advancement toward the ultimate production of good varieties of wheat possessing resistance not only to the hessian fly but also to the most common fungous diseases, including stem rust, leaf rust, bunt, and scab. Through the combined efforts of many workers, numerous sources of fly resistance have been found, and this character has been success-

fully transferred to desirable varieties of commercial wheat. Although progress is necessarily slow, owing to the vast amount of crossing, selecting, and testing involved, the results already obtained and in prospect are encouraging.

RESISTANCE TO OTHER INSECTS

Varieties of wheat have been reported resistant or tolerant to attack by at least 15 insects besides the hessian fly. These insects include the wheat stem sawfly, the wheat stem maggot, grasshoppers, wireworms, the "green grain bug," tipulids, flea beetles, the frit fly, the wheat midge, the wheat stem sawfly, the wheat jointworm, the wheat strawworm, the green bug, and the chinch bug. Breeding for resistance to the wheat stem sawfly is being conducted in Pennsylvania and Canada and for resistance to grasshoppers in the Dakotas and Canada, but with the exception of the work on the hessian fly, little or no extensive testing and breeding to develop resistance to the other insects have been reported.

Durum wheats are generally more resistant to attack by the wheat stem sawfly than varieties of common wheat. Kemp (18) found in 1931 that certain solid-stem varieties of wheat were resistant to attack by this sawfly and suggested that the solid-stem factor be incorporated in certain northern commercial wheats. In correspondence Udine[4] states that workers at the Carlisle, Pa., laboratory of the U. S. Dept. of Agriculture, Agricultural Research Administration, Bureau of Entomology and Plant Quarantine, have established the fact that wheat sawflies have difficulty in maturing in solid-stem wheats. He writes that, "The solid-stem wheats available were of spring habit and were, therefore, not suitable to conditions in the Middle Atlantic States. With the aid of Dr. C. F. Noll at Pennsylvania State College, crosses were made to bring the factor of solid stemness into desirable winter wheats."

Examination of the F_4 generation indicates that solid stemness has apparently been bred into winter wheats. Farstad (11), in studying the nature of sawfly resistance, observed that whenever pith tissue completely filled the lumen of the stem it appeared to constitute a mechanical barrier to the movement of the larvae, and that firm, compact, pithy tissue prevented the larvae from feeding.

Platt (27) found that three partly dominant factors control the expression of hollowness. Solid stem appeared to be influenced by certain environmental conditions in Vulgare wheats, whereas environment had little effect on a solid-strawed durum variety, Golden Ball. Platt, *et al.* (28) crossed solid-stem selections, resistant to the sawfly, with Thatcher and Renown. Studies of the segregating generations showed that solid stems and beards are associated in the cross Renown×S615–9 but not in the Thatcher×S615–11 cross. Neither stem rust nor glume color was associated with solid stems.

Webster (36) found the variety Velvet Chaff to be more highly infested with the wheat stem maggot than Michigan Wonder. Dunham (10), reporting on 4 years' work with a number of spring-wheat

[4]E. J. Udine, U. S. Dept. Agr., Bur. Ent. and Plant Quar., Sept. 19, 1942.

varieties, found Ceres, Hope, and Supreme to be more resistant to stem maggot damage than Reward or Thatcher. Resistance was influenced by seasonal conditions.

For a number of years Allen and Painter (2) observed the reactions of winter wheats to both spring and fall maggot injury. Infestations of the varieties Turkey, Red Rock, Blackhull, and Beechwood were consistently high in all tests. Other varieties, such as Honor, Dawson, Harvest Queen, Tenmarq, and Minturki, had relatively low infestations in all tests. Time of heading was found to be important. Late planting of early varieties, for example, Early Blackhull, may completely reverse the resistance action.

Clark (9, page 223) reported Ceres wheat to be less damaged by grasshoppers than other varieties grown in North Dakota. The durum wheats appear to be particularly susceptible to grasshopper attack. The writer, in 1937, observed four randomly replicated rows of Iumillo and of P. I. 94587 to be completely stripped by a heavy infestation of grasshoppers, whereas 100 rows of spring and winter wheats in the same fly test were uninjured.

Smith (31) in North Dakota found that certain varieties of spring wheat were more injured by grasshoppers than other wheats. Stage of maturity and amount of rust at time of grasshopper feeding appeared to influence the degree of damage.

Jacobson and Farstad (16), in a study of 41 varieties of wheat, found distinct varietal differences in the number of heads cut off by grasshoppers.

Strickland (33), working in Canada in 1931, found in cage tests that plants of Marquis and Reward suffered less injury than Garnet from the prairie grain wireworm. Seeds of Garnet, however, were less damaged than seeds of Marquis or Reward.

Tests by Harris, *et al* (14) in North Dakota show the "green grain bug" (*Chlorochroa uhleri* Stål) to be capable of reducing the yield and grade of grain and of seriously damaging the milling and baking qualities. The damage to 13 varieties of spring wheat ranged from 17% for Renown and 18% for Thatcher to 55% for Kubanka.

Wadley (35) found Mindum (durum) and Vernal emmer to be unfavorable hosts of the green bug.

In correspondence Atkins[5] reports that Marquillo×Oro selections showed relatively high resistance to the green bug at Denton, Tex., as compared with adjoining plats of other varieties. A leaf rust-resistant strain of Mediterranean produced some yield in a number of fields, whereas Tenmarq in adjoining fields was killed by the green bug.

Painter and Bryson (24) report that durum wheats were more heavily infested by the wheat strawworm than Vulgare wheats. Einkorn was not infested.

Painter, *et al.* (25) found a number of clear-cut cases of tolerance to the wheat jointworm in Marquillo winter hybrids. From observations of many varieties of wheat under conditions of severe jointworm infestation, the writer is of the opinion that no winter wheat is immune

[5]I. M. Atkins, U. S. Dept. Agr. Bur. Plant Ind., Sept. 5, 1942.

to infestation, but that hard, strong-stemmed strains generally show little or no breakage and support few galls. Weak-strawed varieties invariably are 100% infested and the straw breakage is severe.

In 1935, Jones (17) studied the reaction of 168 strains of wheat, principally winter varieties, to a heavy infestation of the chinch bug. A classification of strains according to injury, after rains had destroyed infestation, showed 20% of the strains to have suffered little or no injury while 80% were moderately to severely damaged.

That many of the insects mentioned above are of only sporadic occurrence and do less general damage than the hessian fly may account for lack of breeding work to develop strains of wheat resistant to them. From the reaction to attack by the chinch bug, grain bug, jointworm, and some other insects observed in selections of certain hybrids being developed for combined fly and disease resistance, it seems probable that some of these varieties may be resistant to other insects also.

Much groundwork is required in successful crossbreeding to synthesize new insect-resistant varieties. The plant, the insect, and plant-insect relationships must be studied in fullest detail. Environment, degree of maturity at time of feeding, oviposition, development of the insect, composition of the plant as affected by amount of light and soil moisture, and other factors may cause the plant either to escape infestation or to vary in its susceptibility to infestation. The presence of disease and the different biological strains of insects may also affect the reaction of the plant to insect attack. The effects of all these factors must be taken into account in the interpretation of the results obtained in any breeding program if erroneous conclusions are to be avoided.

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INSECT RESISTANCE IN SORGHUM AND COTTON[1]

R. G. DAHMS[2]

SORGHUMS

SINCE the main insect pest of sorghums in the United States is the chinch bug, *Blissus leucopterus* (Say), it is only natural that the major portion of the effort to produce sorghum varieties resistant to insect injury has been concerned with resistance to this insect. Under most conditions, crop plants exposed for the longest time to the attack of a specific insect would be expected to be most resistant to that insect. In distinct contrast to this expectation, however, is the relationship of sorghums to the chinch bug. Neither the chinch bug nor any closely related species is known to occur in Africa or Asia where the sorghums originated. When sorghum varieties were exposed to infestation by chinch bugs in the United States, however, they were found to differ greatly in their resistance to this insect.

Ball and Leidigh (2)[3] were among the first to report the susceptibility of milo to chinch bugs. Since that time many writers have confirmed the susceptibility of milo and called attention to the resistance of kafirs, Darso, and certain sorgos.

Hayes (22) reported that milo crosses exhibiting hybrid vigor were not injured by chinch bugs. Parker (39) and Parker and Painter (40) described the reaction of certain sorghum varieties and hybrids to the chinch bug at Manhattan, Kans., and showed that chinch bug resistance in sorghums is inherited.

The most complete and detailed information on resistance of sorghums to the chinch bug is the work by Snelling and his coworkers (48). They studied the chinch bug reaction of most of the important and standard varieties of sorghums and concluded that, in general, the milos are very susceptible, the feteritas susceptible, and the kafirs and sorgos rather resistant. Most of the sorgos tested by them were slightly more resistant than the kafirs, but others were susceptible. Results obtained by them suggest that resistance is dominant or partially dominant, although the continued manifestation of heterosis in the F_2 generation of the crosses studied may have increased the average resistance to the population. They obtained some evidence in a cross between Sharon kafir (resistant) and Dwarf Yellow milo (susceptible) indicating that one main factor governed chinch bug resistance in this cross. They concluded, however, that there was evidence that the inheritance of chinch bug resistance is more complex and is influenced not only by other genes directly affecting chinch bug reaction but by genetic factors controlling such plant characters

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[3]Figures in parenthesis refer to "Literature Cited", p. 713.

as earliness, vigor of early growth, character of sheath, and others. They also stated that the occurrence of several lines apparently homozygous for intermediate reaction to chinch bugs, and the fact that several hybrid selections were found that were more resistant than the resistant parent, indicated that chinch bug resistance in sorghums is not governed by a single factor.

Snelling and his coworkers also showed that natural selection is an important factor in chinch bug resistance in sorghums. Certain varieties that were apparently homozygous for agronomic characters but which had never been subjected to chinch bug injury were shown to be heterozygous for the genetic factors governing resistance or susceptibility when grown in the presence of chinch bugs. In such cases they were able to increase the resistance of some varieties of sorghums simply by growing them in the presence of chinch bugs and selecting seed from those plants that received the least injury.

Snelling and Dahms (47) and Snelling, *et al.* (48) presented data showing the advantage possessed by early planted sorghums when chinch bug infestation is severe. They reported that early planted sorghums and early maturing varieties were larger when the chinch bugs migrated into the fields and consequently showed the least injury and produced the highest yield.

Snelling, *et al.* (48) made some studies of the cause of chinch bug resistance in sorghums. An attempt to count chinch bugs on plants of Kansas Orange (resistant) and Dwarf Yellow milo (susceptible) growing under field conditions did not indicate preference for the more susceptible variety; but these authors also report that observations in years of light infestation at Manhattan, Kans., showed a high concentration of bugs on susceptible varieties. A count of the punctures (or stylet sheaths) in plants of Kansas Orange and Dwarf Yellow milo indicated that bugs fed about equally on the two varieties. However, approximately equal numbers of punctures were found on the leaf sheaths and blades of Kansas Orange sorgo plants, while on Dwarf Yellow milo there were more than three times as many punctures on the leaf sheaths as on the leaf blades. These authors also studied the relationship between many morphological characters and chinch bug resistance. They concluded that chinch bug resistance or susceptibility is not definitely determined by any one of the gross morphological characters studied.

Dahms and Martin (10) pointed out the difficulty in determining whether the high resistance of F_1 sorghum hybrids is genetic or merely a result of the rapid and heavy plant growth usually exhibited by sorghum hybrids. They determined the resistance of 11 F_1 sorghum hybrids by determining the number of eggs laid by chinch bugs when confined to the stems of the plants. In most of the crosses, resistance as measured by such counts was dominant to susceptibility. The extent of hybrid vigor as measured by height of plant, diameter of stalk, and number of tillers did not appear to be definitely associated with chinch bug resistance as measured by oviposition and longevity of the females.

The preference of chinch bugs for seedling sorghum varieties and the tolerance of several varieties to a uniform chinch bug attack was

studied by Dahms, Snelling, and Fenton (11). These authors also determined the effect of different sorghum varieties on the oviposition and longevity of the adult chinch bugs and the rate of development and mortality of chinch bug nymphs when confined to resistant and susceptible varieties. In a series of tests on the preference of the chinch bug to Dwarf Yellow milo (susceptible) and Atlas sorgo (resistant), 80% of the bugs were attracted to the susceptible variety. They also found that 10-inch plants of Atlas sorgo lived longer than plants of the same size of Dwarf Yellow milo under the same chinch bug infestation. Chinch bug females lived longer and laid many more eggs on the susceptible variety Dwarf Yellow milo than on any of the other varieties tested, and nymphs reared on Dwarf Yellow milo developed more rapidly and had lower mortality than those reared on Atlas sorgo.

Dahms and Fenton (9) found that the resistance of both resistant and susceptible varieties was consistently decreased by the addition of sodium nitrate to the soil, and in the majority of cases was increased by addition of superphosphate.

A discussion of the possible mechanism of chinch bug injury to sorghums was given by Painter (38). The object of the insect puncture on the plant is to reach the phloem tubes, and it is suggested that plant injury may come from stoppage of the tubes with a secretion. Tannins are also suggested as a possible factor in resistance.

Webster and Mitchell (57) studied the nitrogen fractions in field-grown Atlas sorgo and Dwarf Yellow milo plants and found that the milo plants were higher in nitrogen content than the Atlas plants. Most of the differences in soluble nitrogen content between the two varieties could be accounted for in the basic and alpha amino nitrogen fractions.

After more detailed chemical analyses of Atlas sorgo and Dwarf Yellow milo plants, Webster and Heller (58) reported the following differences: (a) Milo always contained some sucrose, and generally contained large amounts, whereas Atlas rarely contained any appreciable amounts; (b) the total nitrogen content of Atlas normally decreased with growth whereas milo percentages increased; (c) the chlorides values were usually higher in milo; (d) milo plants were generally found to be higher in phosphorus, potassium, and calcium. Analyses were also made on the two varieties and no significant differences were indicated in the following: (a) Solids content of the juice; (b) acidity measurements; (c) astringency values, including tannins; (d) conductivity; (e) catalase, oxidase, and peroxidase activity; and (f) hydrocyanic acid content.

No sorghum variety has been obtained that is immune to the chinch bug, but progress has been made in the development of resistant varieties by hybridization and selection. Types resembling feterita and milo have been developed that are much more resistant than the original varieties.

The resistance of sorghums to other insect pests has received some consideration. Hsu (25) reported on the resistance of 1,073 sorghum strains to the stem borers, *Pyrausta nubilalis* (Hbn.) and "*Diatraea diatraea*", at Peiping, China. His data indicated that the extent of

infestation differed among varieties. Under controlled conditions, sorgos as a group were more susceptible to these insects than the nonsaccharine varieties. He suggests that host selection of the "laying" moths is a possible cause for the varying degree of infestation in different varieties. White grain varieties showed less infestation by borers than varieties with other grain color. The reason for this relation is unknown, however, and he suggests that possibly some other characters associated with white grains may be important factors in borer resistance.

Riley, *et al.* (45, page 252), Helder (23), Dean and Kelly (12), Milliken (35), Hume (26), and Hume and Franzke (27) all called attention to the resistance of sorghums to grasshopper injury compared with that of corn. This fact was brought out by Brunson and Painter (5), who also reported that observations in the sorghum nursery showed slight but consistent differences in grasshopper injury to different varieties. In general, injury to the sorgos and the kafirs was less than to milo and to some of the newer varieties originating from hybrids involving milo.

The only mention in the literature in regard to resistance of sorghum to the corn leaf aphid, *Aphis maidis* Fitch, is by McColloch (34). He stated that all varieties studied were attacked by this insect, but that apparently there was a difference in injury of the different varieties.

All sorghum varieties appear to be susceptible to the sorghum midge, *Contarinia sorghicola* (Coq.), but quickly maturing varieties, such as feterita and milo, planted early, usually produce grain before the midge appears in sufficient numbers to do serious damage. Ball and Hastings (3) reported that Sumac sorgo seemed to be practically resistant, probably owing to the very short glumes; and Karper, *et al.* (31, page 44) stated that Shrock seemed to produce seed better under midge conditions than other varieties. Cowland (8) reported that in Sudan some varieties seemed to be more resistant than others. Walter (54), after testing the reaction of 43 varieties of sorghum to the midge, made the following statement: "So far no varietal resistance has been definitely shown and all varieties seem to be attacked to the same degree. Such differences as were observed at San Antonio appeared to be due to the greater uniformity in blooming in some varieties than in others or to the influence of varied growing conditions in different plots on the length of the blooming period."

The use of resistant varieties to lessen injury from insects that attack sorghums would appear to deserve more attention, because the control of insects on a crop of low value per acre precludes the use of insecticides. Furthermore, there is a possibility that the growing of resistant varieties would reduce the insect population; this certainly would appear to be true in growing chinch bug-resistant sorghums, since the resistant varieties have been shown to have an adverse effect on the chinch bug.

COTTON

Several entomologists and agronomists in the United States and in other countries have studied cotton varieties in relation to various

cotton insects, and some progress has been made in controlling some of these insects by the use of resistant varieties or of varieties which, through earliness or some other characteristic habit of growth, escape serious infestation by one insect or another.

Soon after the boll weevil, *Anthonomus grandis* Boh., was discovered in Texas, the U. S. Dept. of Agriculture (55, page 687) sent an expedition to Guatemala to investigate the production of cotton there under boll weevil conditions. Members of this expedition found a dwarf upland variety of cotton that was much less injured by the weevil than nearby cottons. Protective morphological structures possessed by this type were the effective proliferation, small involucral bracts, and excessive hairiness over the plant surface. Seed of this cotton was brought back to the United States, but no boll weevil-resistant variety was ever developed from it.

In 1906 and 1907, G. N. Collins and C. B. Doyle made a trip into southern Mexico to investigate cotton culture under boll weevil conditions in that region. They brought back seed of an upland cotton which later became known as Acala. This variety and certain selections from it have been grown under conditions that demonstrated its resistance to drought and ability to produce crops in a short period in spite of boll weevil infestation.

Hinds (24) made extensive studies of proliferation as a factor in the control of the weevil. He showed that in some cases, when the boll weevil disturbed the cells of the square or boll, numerous elementary cells developed from the parts of the square or boll near the injury. These growths would often kill the larvae of the weevil by pressure. He found that the average mortality due to proliferation was 13.5% in squares and 6.3% in bolls. Proliferation in the varieties he studied ranged from 12.9% to 75.6%. There is no indication in the literature that the percentage of proliferation of recently developed cotton varieties has been investigated.

Early production of cotton and the use of early fruiting, rapidly maturing varieties have been recommended as a means of reducing boll weevil injury ever since the weevil was first introduced into the United States. On the basis of date of boll opening, many of the early maturing cottons are short-stapled varieties. Cook (7), however, pointed out that date of boll opening is a poor criterion for earliness, as far as its relation to boll weevil damage is concerned. He comments that, since the weevil does not injure the mature boll, the primary object is to produce many bolls in a short time, and it is not necessary to select short-stapled varieties to get a cotton of this type.

Lewis and McLendon (33) stated that the ideal cotton plant to be grown when the boll weevil is present should begin fruiting close to the ground early in the season, and have long fruiting branches at the base that continue to grow throughout the season. They also stated that, under boll weevil conditions, the more cotton that is produced on the lower half of the plant, the larger will be the yield per acre.

Isely (30) made studies to determine what part of the increase in yield of early maturing varieties was due to reduced boll weevil injury and what part to other factors. His results showed clearly that late-maturing varieties carry a much greater weevil hazard and also

that there is less to be gained by dusting on an early, rapidly maturing cotton. He pointed out that the natural fruiting period of a variety is greatly modified by the moisture supply, the soil type, and the soil management. Thus varieties that usually have a long fruiting period in the bottoms may have a short, almost determinate fruiting period in the light sandy uplands.

Fenton and Dunnam (17) made a study of boll weevil damage to cotton bolls and comparative cotton loss on two varieties of short-staple and one variety of long-staple cotton. They found a difference in the susceptibility of different varieties to boll damage by the weevil. Cotton loss of less than 10% resulted from weevil attack on the long-staple and one short-staple variety after the bolls were 20 days old. The other short-staple variety was more susceptible, the weevil being able to cause more than 10% damage up to 30 days after blooming.

In a study of cotton-boll growth in relation to boll weevil injury, Dunnam (14) found that as the cotton bolls grow older they are less susceptible to injury by the weevil and that the injury at given ages varies with the variety. He found no correlation between the numbers of feeding and of egg punctures and the percentage of cotton loss. Neither did he find any relation between the thickness of the hull and susceptibility to weevil damage in spite of the fact that the weevil lays fewer eggs on the thick-hulled varieties. He concluded that the determining factor is the hardness of bolls, because varieties with the hardest bolls, as determined by the number of grams pressure required to puncture them, showed also the lowest percentage of cotton loss.

Isely (29) made a study on the relation of leaf color and leaf size to boll weevil infestation in eight green-leafed varieties and four red-leafed varieties. He found that the boll weevil infestation in the red-leafed varieties was considerably less than in the green-leafed varieties. The average infestation in the green-leafed and red-leafed plots, respectively, on August 17 was 43.87 and 14.25; on August 24, 53.94 and 16.12, and on August 31, 58.62 and 32.25%. In this paper Isely reported that the boll weevil apparently makes little choice between small- and large-leafed varieties, provided the size and vigor of the plants are about the same.

An investigation of the varietal character of cotton in relation to attack by the boll weevil was reported by Strong (50, page 54). Of 44 varieties of cotton studied, those producing bolls with walls of medium thickness were less damaged by the weevil than those with either thick or thin boll walls. A negative correlation was found between boll-wall thickness and toughness of the carpel lining as measured by a resisto-meter.

Sea island cotton is known to be much more susceptible to the boll weevil than the upland varieties. The rind of the sea island cotton is thin and easily penetrated by the weevil, and the bolls remain subject to weevil injury during the entire maturation period. Moreover, the fruiting of sea island cotton is not sufficiently early or uniform and the period of boll development is too long to enable the plants to escape devastation by the weevil. Breeding work, according to Ware (55, page 690), has not been very effective in furnishing strains that

would provide any assurance of a crop under heavy infestation by the boll weevil. Recently it has been reported, however, that earlier strains of sea island cotton are now being developed which will escape injury by this insect to some extent. Some breeding work with extra-long-staple upland varieties has also been carried on to obtain suitable upland strains to replace sea island where the latter cannot be grown on account of weevil damage. Meade, an upland variety developed in Texas, has fiber that somewhat resembles that of sea island cotton. When this variety was grown in southeastern Georgia under severe boll weevil conditions, it yielded three to four times as much as sea island cotton. However, soon after this variety was developed it became contaminated and mixed with the fuzzy-seeded upland cottons. Breeding and selecting is now being done with this variety and with other varieties like Tidewater, Wilds, Ewings Long Staple, hybrids among these, and hybrids of these and sea island.

Perhaps the outstanding example of resistance by cotton to insects is its resistance to the cotton cicadellids, or leafhoppers, which include *Empoasca facialis* (Jac.), *E. devastans* Dist., *E. terrae-reginae* Paoli, and probably others. These insects sometimes seriously injure cotton in Africa, India, and Australia. At least one variety has been found that is completely immune to cicadellid attack, and some other varieties are very resistant. The resistance of cotton to these insects has been reported by Parnell (41, 42), Worrall (60, 61), Lal (32), Sloan (46), Moerdyk (36), and others. They all agree that the chief factor in resistance is the hairiness of leaves. Lal studied the resistance of seven varieties of cotton to cicadellids and found that the resistant varieties had short hairs and extreme hairiness. The most hairy American varieties, which also had the greatest average hair length, were not the most resistant. Some evidence obtained by Lal indicated that resistance to cicadellid attack may be due to some peculiarity of the veins that prevents oviposition. Parnell (41, 42) reported that the Cambodia variety introduced into South Africa from India was the only variety that showed complete immunity to *Empoasca facialis*. All newly imported American varieties were very highly susceptible. He states that all resistant plants were distinctly hairy but that all hairy plants were not necessarily resistant. Degree of hairiness and length of hairs are both concerned. Of several varieties tested by Parnell, one variety with comparatively sparse and very long hairs was highly resistant, two with high density and long hairs were very resistant, and two varieties with sparse hairs of moderate length were very susceptible. The most highly susceptible types of all had the fewest hairs. No extremely hairy types have yet been found with very short hairs.

Worrall (60) studied the resistance of American upland cotton to the cicadellid. He reported that in most fields individual plants could be found that were resistant and that these plants were thickly covered with hairs on leaf, stem, and bracts. Sloan (46) observed that cicadellid-resistant cottons imported experimentally from South Africa into Queensland remained resistant to the cicadellid but were inferior in quality. He found that resistant plants were typically hairy on the lower surface of the leaves, petioles, stems, and bracts.

Very little information is available on resistance of cotton to the bollworm, *Heliothis armigera* (Hbn.). Parnell (43) found that the adult moth was attracted particularly to the better developed plants and preferred the more fruitful varieties, so the best strains were likely to be most damaged. As a result, poorly developed and lightly fruiting types sometimes yielded more than good, heavily fruiting types nearby. Pomeroy (44) stated that bollworms did not damage American cotton so much as native Nigeria cotton because the developmental period of the former was shorter.

Ballou (4), Chapman (6), and Storey (49) all agree that early ripening varieties of cotton are of considerable importance in minimizing attacks by the pink bollworm, *Pectinophora gossypiella* (Saund.). Chapman (6) tested a number of varieties but found all of them to be 100% infested. However, there did appear to be some indication that the grade was not lowered so much in the varieties with high lint percentages or high lint index as in the varieties with low lint percentages or low lint index. The results of spacing tests indicated that close spacing hastened maturity and tended to reduce the late seasonal pink bollworm damage. Audant and Occenad (1) found native Haitian perennial cotton resistant to attack by the pink bollworm. They stated that when the native cotton was grown in experimental plats beside many other kinds of cotton its resistance to pink bollworm attack was very marked. When this cotton was grown commercially in absence of other varieties, the pink bollworm practically ceased to exist.

Wolcott (59) found many pink bollworms in Haiti in 1924 but had difficulty in finding native cotton infested, although all other varieties were highly infested. It is not known whether Haiti native cotton will retain its resistance outside the West Indies.

Pomeroy (44) noted that cotton stainers, *Dysdercus* spp., preferred American cottons over indigenous Nigerian cotton. Parnell (43) found that injury by stainers was greater on cotton with a bushy, leafy growth. He stated that this might have been wholly or partly due to its greater attractiveness and consequent heavier puncturing of the bolls, increased infection by the fungus involved, or difference in the physiological condition of the bolls and their reaction to infection. Strong (51, page 70) reported that 31.5% of the bolls of short-staple cotton in Arizona were punctured by pentatomids and capsids as compared with 14.6% of bolls of long-staple varieties. Mumford (37), in a preliminary study of the effect of climate and soil conditions on the resistance of cotton to the cotton stainers, found that the disturbance of the water balance in the cotton plant increased its susceptibility to cotton stainers. He suggested that this condition rendered the sap more attractive by altering the concentration or constitution of the carbohydrates in it. He also suggested that the chemical composition of the soil is important in affecting the susceptibility of the cotton plant to insect attack.

In recent years considerable work has been done in Texas and more recently in Oklahoma on the resistance of cotton to the cotton flea hopper, *Psallus seriatus* (Reut.). Thomas, *et al.* (53) tested 20 varieties of cotton and found considerable variation in the ability of different

varieties to retain squares in the presence of a slight flea hopper infestation. Certain varieties appeared to possess a high degree of resistance, whereas other varieties grown under the same conditions lost a large proportion of minute squares. Gaines, *et al.* (18) found that early and late-maturing varieties had higher flea hopper infestation than intermediate varieties. Strong (52, page 80) reported that the seasonal flea hopper infestation of four varieties of cotton with different plant and growth characteristics was more than twice as high in the most susceptible as in the most resistant variety. There was also a marked varietal difference in the injury by flea hoppers in the untreated cotton and some indication that insecticides were more effective against the flea hopper on some varieties than on others.

Dunlavy, *et al.* (13) suggested that the Acala 8 strains seemed to be more susceptible to flea-hopper attack than other types. They also found that the size of the boll of some varieties was reduced. Acala 8 strains and many Mebane strains were adversely affected in this manner, but the Stoneville and Lankart strains were not.

The effect of time of chopping and number of stalks per hill on infestation of thrips, *Frankliniella* spp. and *Sericothrips variabilis* (Beach), was studied by Dunnam and Clark (15) on 40 varieties of cotton. They reported varietial variation of 13.8 to 5.5, 40.34 to 5.0, and 38.56 to 11.24% of terminal buds destroyed under three conditions of growth, but they did not state whether the same varieties were low or high in each condition. They concluded that no difference in varietal infestation was observed, but suggested that the type of terminal bud in different varieties might have had some effect on the damage. Nevertheless, there were six varieties which produced more seed cotton on the injured plants than on normal plants, indicating a difference in the ability to produce cotton in spite of thrips injury. Watts (56) noted that late cotton regularly suffered more thrips injury than did that planted early.

Harland (20) reported that the nigra, or black, scale, *Saissetia nigra* (Nietn.), was a serious pest of sea island cotton when it was first introduced in the West Indies. However, two types of Seredo cottons were quite immune to this scale, the immunity being inherited and in breeding experiments behaving as a partial dominant.

The immunity and inheritance of immunity of cotton to the cotton blister mite *Eriophyes gossypii* Banks, which sometimes is a serious pest to cotton in the West Indies, has been studied by Harland (19, 21). West Indies cottons are in two groups in regard to this pest; thus (a) they may be immune or (b) they may be attacked although still fairly resistant. Sea island cotton is very susceptible. In general it may be said that the nearer an indigenous cotton approaches the sea island variety in morphological characters, the more susceptible it may become. In a study of budded cotton, Harland found that the only scion which remained immune was one that was budded on the susceptible sea island stock. When a susceptible scion was budded on immune stock, the resistance was apparently increased; but when the stock was fairly resistant and the scion susceptible or *vice versa*, the susceptibility or resistance of the scion remained unchanged. Harland studied the F_1, F_2, and F_3 generations of a cross between immune and

susceptible types. The F_1 was intermediate though inclined toward the susceptible parent. In the F_2 generation, segregation occurred into immune and nonimmune; and in F_3, immune bred true while nonimmune segregated into immune and nonimmune. Although these results would seem to indicate that immunity to the cotton blister mite is definitely an inherited character, Harland (21) says, "* * * it is the opinion of the present writer that immunity to this mite is not yet shown to be inherited as a simple Mendelian factor."

The effect of pilosity of cotton on the population of the cotton aphid, *Aphis gossypii* Glov., was studied by Dunnam and Clark (16). The aphid population found on undusted cotton was in direct proportion to the number of hairs per square millimeter on the lower leaf surface where this insect was breeding. In one test the pilose cotton, as compared with the almost glabrous cotton, had 5.8 times the number of live aphids. No varieties have been found that are immune.

Husain, *et al.* (28) found that the cotton whitefly, *Bemisia gossypiperda* Misra and Lamba, fed and laid more eggs on cotton with tender leaves. It infested indigenous Indian varieties more severely early in the season and American types in July and August. They found that this was primarily due to the pH of the cell sap. The relative incidence of infestation corresponded with the trend of the pH curve, indicating partiality toward higher pH values.

As shown by the examples mentioned, there appear to be definite possibilities in reducing insect damage to cotton by the use of varieties that possess actual resistance to insects or certain habits of growth that enable them to escape insect infestation. The use of such varieties, however, probably will never entirely replace insecticides as a means of controlling the major cotton insects. Nevertheless, the fact that several of these can be controlled by the application of insecticides does not necessarily reduce the value of resistant varieties, because there are always some farmers who are not prepared to apply insecticides. There is also an advantage in the saving of labor, money, and material through the development and use of resistant varieties. Resistant varieties would be particularly valuable against such insects as the pink bollworm, because no effective method of insecticidal control is yet known. Even after resistant varieties are developed, further breeding work will be necessary because of the continuous danger of their becoming contaminated and mixed with other varieties, both by cross pollination in the field and by mixture of seed at the gin.

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INSECT RESISTANCE IN FORAGE PLANTS[1]

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BECAUSE of the relatively low per acre value of forage crops, cultural methods and the use of resistant strains appear to offer the best means of controlling insects that attack forage plants. The definition of insect resistance that seems to be generally accepted is given by Snelling (30)[3] as "those characteristics which enable a plant to avoid, tolerate or recover from the attacks of insects under conditions that would cause greater injury to other plants of the same species."

References pertaining to this subject were obtained from the bibliographies by Snelling (30) and Platt and Farstad (23). Further information on the most recent developments in this field was obtained by correspondence from a number of the men working on these problems.

Studies on insect resistance in forage plants have been limited to a very few insect species, some of which affect more than one type of forage plant.

POTATO LEAFHOPPER

The potato leafhopper, *Empoasca fabae* (Harr.), causes widespread damage, especially in the eastern half of the United States, to a wide variety of plants, including apple, potato, clovers, alfalfa, beans, and peanuts. Of all the forage plants, alfalfa appears to be the most seriously damaged by this insect. Jones and Granovsky (19) were perhaps the first workers to demonstrate experimentally that this leafhopper caused the disease-like condition known as "alfalfa yellows." The attack of the leafhoppers causes the leaves to turn yellow, then bronze or purple, and die prematurely. New leaves formed after the attack are much smaller than normal, the internodes of the stems become much shortened, and the whole plant may become stunted. On the older stands the second and third crops are the most heavily infested and the "yellows" may result in increased winterkilling, although tests by Jewett (14) in Kentucky did not show this to be the case there. New stands may be killed outright. Records indicate a measurable reduction in hay yield of from 14 to 50%. Poos and Johnson (26) have shown that the severity of injury is directly correlated with the number of leafhoppers present.

Smith and Poos (28) and Smith (29) attribute the damage to a disease-like injury resulting from the deposition in the vascular tissue of a highly insoluble sheath that probably interferes with the normal

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[3]Numbers in parenthesis refer to "Literature Cited", p. 723. In addition, the following men wrote letters to the author telling of the status of work at their several institutions on resistance of forage crops to insect attack: T. R. Chamberlain, L. G. Jones, C. J. Sorenson, and V. L. Wildermuth.

translocation of plant materials. Johnson (17) concludes that the injury is not due to any specific agent but to an accumulation of the carboyhydrate products of photosynthesis where a plugging of the phloem tissues is caused by the leafhoppers.

Apparently none of the commonly grown commercial types of alfalfa are resistant to the potato leafhopper. Considerable variation, however, occurs in the amount of damage within alfalfa strains. Poos (unpublished correspondence) mentioned the fact that one coarse-stemmed selection studied at Arlington Farm, Va., stood up well under heavy leafhopper populations, and that some of the pasture types are fairly resistant. As far as can be determined, no attempt has been made to utilize resistant types for the purpose of breeding resistance into the commercially grown alfalfa varieties.

The potato leafhopper affects susceptible varieties of red clover in much the same way as it does alfalfa. The relationship between the potato leafhopper and the yellowing and dwarfing of red clover was suspected by a number of workers but was first demonstrated by Hollowell, Monteith, and Flint (12). The pubescent types of American clovers are not seriously affected, whereas the more glabrous English, French, and Italian varieties are severely damaged. Pieters (25) attributes the resistance shown in the American types to natural selection during the 200 years or more that these clovers have been cultivated in America. He records the supposition that the resistant hairy types set more seed than the susceptible smoother types, thereby gradually replacing them. Poos and Smith (27) found that, in general, the rough-hairy pubescent varieties within a species usually were less damaged than the nonpubescent or appressed-pubescent varieties. In certain varieties, however, the rough-hairy pubescence was not the prime reason for their greater resistance. In later tests Poos and Johnson (26) found that when leafhoppers were allowed a choice, 74.6% of the total nymphs hatched on glabrous Italian clovers and only 25.4% on a native rough-hairy Ohio strain. Jewett (14) suggests the possibility that characters other than pubescence might also be responsible for resistance. He (15.16) found a positive correlation between the comparative resistance of five varieties of red clover and the resistance of their leaves to puncturing.

From their studies on the effects of the potato leafhopper on soybeans, Hollowell and Johnson (13, 18) concluded that freedom from injury by this insect is correlated with the occurrence of rough-hairy pubescence. Studies of the F_3, F_4, and F_5 generations from a cross between the rough-hairy Illini variety and a dominant glabrous soybean were made. In all three generations the homozygous glabrous and heterozygous progenies were all heavily damaged and stunted. The homozygous rough-hairy lines were entirely free from injury and grew vigorously. Glabrous and appressed-hairy soybean introductions from the Orient were also studied. The glabrous types were severely damaged while the appressed-hairy types showed no marked injury, although some yellowing of the leaves occurred. Some of the glabrous strains included individual rough-hairy plants that were free from leafhopper injury. It would therefore appear that any new commercial varieties produced for growing in the eastern half of the

United States will need to be of the rough-hairy or appressed-hairy types if leafhopper damage is to be avoided.

PEA APHID

The pea aphid, *Macrosiphum pisi* (Kalt.), causes widespread damage to a number of forage plants, including peas, alfalfa, red clover, and vetch. In the case of alfalfa certain cultural methods of control have been partly successful, but the development of resistant strains seems to offer the most possibilities.

Blanchard and Dudley (7) observed alfalfa plants that escaped damage in badly damaged fields in California and in the course of greenhouse tests in Wisconsin. The tests reported by Dudley in 1934 and tests of F_3 lines made subsequently by R. A. Blanchard and L. G. Jones showed some strains to be practically immune to the pea aphid. More recent unpublished work by L. G. Jones and F. N. Briggs has shown that aphid resistance is an inheritable character and that modern breeding methods can be used in the development of aphid-resistant as well as agronomically desirable lines.

Painter and Granfield (24) observed wide variations in the amount of damage in, and the number of aphids swept from, different varieties of alfalfa in test plots in Kansas. The variety Ladak had only 10% of injured plants as compared with 70% for Turkestan No. 19316. Eichmann and Webster (10) confirmed the resistance of Ladak in Washington but doubted its suitability for forage in that state.

In 1936, Albrecht and Chamberlain (3), in greenhouse tests of seedling F_2 hybrid progenies of the resistant strains isolated in Wisconsin, obtained results similar to those obtained by Dudley. In a repetition of the tests in 1937, using year-old plants, little difference in reaction between the progenies of resistant and susceptible parents was observed. Poor illumination and occasional subjection of the plants to low temperatures was mentioned by the authors. They conclude, however, that resistance in these plants was not a stable character and that until the relation of environment to the expression of resistance to aphids is better known, it is impractical to determine the precise manner of inheritance of the resistant character. Blanchard (unpublished notes) likewise observed that poor illumination resulted in modification of resistance.

Dahms and Painter (9) tested individual plants selected on the basis of having shown definite resistance or susceptibility in field plots. They also selfed these selections and tested the progeny. A wide variation was noted in the rates of aphid reproduction and percentages of aphids dying on the parent plants. One resistant selection (Turkestan F. C. 19316) allowed an average increase of less than 1 aphid per parent and a mortality rate of over 80% under temperatures of 78°, 61°, and 57° F, respectively. At 61° an average of 7.4 aphids per female was produced on 16 other resistant plants and 46.2% were dead at the end of 10 days, as compared with 27.3 aphids per female and 2.2% mortality on 10 susceptible plants. At 44° there was an increase of 8.9 aphids per female and a mortality of 1.0% on the resistant plants as compared with a 9.9 aphid increase and only 0.1% mortality on the susceptible plants. On the progeny of 12 selfed resis-

tant selections there was an average increase of 0.9 aphid per female in 10 days as compared with an average of 5 per parent on the progeny of selfed susceptible selections. Aphids confined to the flowering branches in these tests reproduced much faster than those confined to vegetative branches of the same plant.

No single plant character has been definitely associated with resistance of alfalfa to the pea aphid. It appeared at one time that the resistant lines from the California material were a deeper green than susceptible lines. As mentioned earlier, resistant lines which lost their green color because of poor illimination also tended to lose their resistance. Aphids feeding on the immune or highly resistant lines gradually became shrunken and dark green and were restless upon the plants.

Unpublished studies by W. T. Emery at Manhattan, Kans., indicate that pea aphid resistance in alfalfa may be correlated in part at least with the proportion of schlerenchymatous tissue, and of lignin in the walls of the parenchyma of the rays, in the growing shoots.

Albrecht (2) observed differences among both species and varieties of vetch in resistance to the pea aphid. More than 20 species and varieties were observed during severe infestations in 1937 and moderate infestations in 1938 and 1939. Based on foliage injury 10 strains were resistant, 8 were susceptible, and 8 highly susceptible. Of four selections from *Vicia sativa* No. 34947, one was severely injured, two slightly injured, and one was unharmed. Of 40 hairy varieties of *V. villosa* included in a progeny test, 10 were injured by the pea aphid. Field observations and cage tests showed that the green pods and inflorescences of both resistant and susceptible varieties could be severely damaged by aphids. This is given as one of the reasons for small seed production in the vetches studied.

CHINCH BUG

An interesting study of the reaction of a hundred species of grasses to attack by the chinch bug, *Blissus leucopterus* (Say), was made by Hayes and Johnston (11) in a special grass garden at the Kansas State Agricultural College at Manhattan. The grasses in this garden suffered from a severe infestation of bugs migrating from nearby wheat plots. They state, ". . . those grasses having harsh tissues seem, in most cases, to be especially resistant, if they are native grasses. For example, such a plant as *Andropogon scoparious* has harsh tissues and is a native perennial. . . . In the majority of instances of those grasses termed 'harsh' in which chinch-bug injury was severe and recovery poor, the species were introduced ones." Among the plants with tender tissues they observed only one species (a native species) which showed but slight damage. A few species showed only moderate injury. The majority of tender grasses were either severely injured or completely killed. They noted one instance, in the case of *Hystrix hystrix*, in which the age of the grass seemed to make no marked difference in the ability of the plant to withstand injury. Bunch types were alike slightly injured or killed, and the same can be said of the turf, tufted, and dispersed types. They noted that several

species had matured and produced seed before the migration of the chinch bugs from the wheat to the grasses.

JAPANESE BEETLE

Studies of differential injury to soybean varieties by the Japanese beetle, *Popillia japonica* (Newm.), are summarized in several unpublished reports of studies carried out by workers of the U. S. Dept. of Agriculture and of the New Jersey Agricultural Experiment Station. Keim (20) reports on 92 varieties and strains. He states that varietal differences in damage by the Japanese beetle do occur. Varieties of soybeans with dark-green leaves appeared to be less relished by the beetles than those with lighter leaves. He doubts whether color alone is responsible for this reaction, and it is his opinion that there are good possibilities that resistant commercial varieties can be secured through selection and breeding. According to Keim, similar work by I. M. Hawley conducted independently on the same plots resulted in almost identical conclusions.

T. N. Dobbins tested five soybean varieties in New Jersey in 1940, and J. L. King tested the same varieties in 1941 (unpublished reports to the Bureau of Entomology and Plant Quarantine). Although none of the varieties tested were immune to attack, there was a significant difference between varieties in amount of damage to the foliage. The differences in weight between beans from damaged plots and those from undamaged plots were not significant, however, when differences in potential yield between varieties were taken into account. These results indicated that in neither of the two years was the injury caused by the beetle to the foliage a significant factor in reducing either the number of pods or the weight of beans produced. In personal conversation, W. P. Flint mentioned that in test plots conducted in New Jersey by J. L. King in 1942, the amount of foliage destroyed ranged from 15% for resistant varieties to over 50% for the more susceptible ones.

CLOVER SEED MIDGE

Metcalfe (22) reports white clovers as being immune to the clover seed midge, *Dasyneura leguminicola* (Lintn.), under insectary conditions and in field plots. She found a variation in percentage of damaged heads and the number of larvae per head between several varieties of red clovers but thought that this variation was due to time of flowering rather than to any resistant character in the plants.

COWPEA CURCULIO

Tests of garden variety cowpeas for differential damage by the cowpea curculio, *Chalcodermus aeneus* Boh., are reported by Arant (4) and Bissell (5, 6). Arant found considerable variation between varieties in the number of peas damaged by this insect but was of the opinion that the resistance in the varieties tested was not of high enough order to provide control where the varieties are grown alone. In later tests Bissell also found considerable difference between varieties in the percentage of damaged peas. Puncture tests showed a

correlation between low degree of curculio injury and both toughness of pod and pea and smallness of seeds. Bissell considers time of bearing of more influence than variety upon damage by the curculio, the later plantings tending to be the least damaged. La Conch, one of the varieties reported by both Arant and Bissell as being resistant to the pea weevil, was also reported by Arant to be resistant to nematodes and adverse weather.

LYGUS, spp

Aamodt and Carlson (1) state that alfalfa varieties differ considerably in their ability to flower in spite of *Lygus* bug injury. Bugs were present in all varieties in about equal numbers, and the difference in flowering apparently resulted from the differences in ability of the varieties to recover from damage. Grimm alfalfa showed the most resistance in their tests, and Turkestan, Cossack, and Ohio Common were the most susceptible. Certain strains of Grimm were reported as being more resistant than the average of that variety.

FRIT FLY

Cunliffe (8) studied at least 70 varieties of oats from various parts of the world for resistance to the frit fly, *Oscinella frit* (L.). This fly causes widespread damage in Europe to oats as well as wheat and many other species of the grass family. Summer, a Swedish variety of oat, was the most resistant. Cunliffe crossed this variety onto the varieties of agricultural importance in England and concluded from a study of these crosses that resistance to this insect was a definite, inheritable character. Selection for 8 to 10 generations reduced the character to a considerable degree of purity, although the resistance was not of a high order. He suggests that reduced damage in the resistant varieties may be due to increase in crude fiber or deposition of silica.

GENERAL CONSIDERATIONS

Several authors have called attention to the possibility of reducing injury by a particular insect to more than one crop through the development of resistant strains of crops that serve as alternate hosts. Dudley, Eichmann, and Webster (10), and others have mentioned this possibility with regard to the pea aphid. Since alfalfa and the clovers serve as primary hosts from which this aphid migrates to peas in potentially injurious numbers, it might be possible to reduce damage to peas through the development of highly resistant varieties of alfalfa and clover. This would, of course, necessitate the general use of these varieties in the pea-growing areas. The same principle could perhaps be applied to the control of the potato leafhopper or any other insect having several host plants. Reduction in the size of insect populations through the development of resistant strains might also conceivably reduce the chances of transferring insect-borne diseases from plant to plant within plant types as well as between plant types.

Another consideration is the fact that insect resistance is sometimes variable in nature. Variability in resistance to the pea aphid of the

same alfalfa selections under different environmental conditions has already been mentioned, and other similar reactions are noted in the literature. For instance, Lees (21) gives 14 cases in which susceptibility to insect attack may vary with conditions under which the plant is growing. This fact should not deter workers in their efforts to develop resistant plant strains, but it should make them more cautious in accepting strains as being resistant. It should also make apparent the necessity of understanding the conditions favorable to the insect-plant relationship and of attempting to provide these conditions in conducting tests.

The fact that one part of a plant is resistant to an insect is no assurance that another part of the same plant is resistant also. Attention has already been called to the susceptibility to the pea aphid of the floral and seed-bearing portions of alfalfa and vetch plants, the vegetative parts of which were resistant. These are examples of what appears to be a fairly general condition.

DISCUSSION

From a survey of the literature it appears that there is more evidence of resistance in forage crops to sucking insects such as the pea aphid and potato leafhopper than to the chewing insects.

Very few cases of the development of insect-resistant commercial varieties of forage plants were found in the course of this review. Strains highly resistant to the pea aphid, the potato leafhopper, and certain other insects are reported by careful observers. That there is a pressing need for the development of forage crops resistant to these insects is a matter of general knowledge. Why, then, has not greater progress been made along this line?

Several reasons may be advanced in answer to this question. In the first place, the concept of insect resistance in plants, while it goes back at least 150 years, has not received wide attention until in comparatively recent times. In the second place, the fact has only recently been recognized that insect resistance, when it can be found, is transmissible like other plant characters, and can be included in a general breeding program. In the third place, the attainment of the objectives of such programs requires a considerable period of time.

Although resistance to some insects may be correlated with an easily observable plant character, that is by no means always the case. It would therefore appear that rapid progress in developing resistance in forage crops to most insects can be made only by subjecting crosses involving resistant and susceptible strains to severe insect infestations. Since severe insect damage does not always occur year after year in breeding plots, methods of artificially subjecting breeding material to severe insect tests would no doubt result in more rapid progress. The entomologist could perhaps be of greater assistance in this regard if ways and means were brought about of integrating his knowledge and resources into the breeding programs. One need only drive across certain sections of the country east of the Mississippi to observe the need for strains of alfalfa, beans, and other legumes resistant to the potato leafhopper. The same may be said for other

insects in other parts of the United States. A closer cooperation between the agronomist, plant breeder, and entomologist might hasten the alleviation of this condition.

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INSECT RESISTANCE OF PLANTS IN RELATION TO INSECT PHYSIOLOGY AND HABITS[1]

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INSECT injury to plants results principally from the feeding of insects and studies of insect resistance in plants, particularly the causes of resistance, must primarily be concerned with how insects find and utilize food. The planning and execution of experiments dealing with resistance requires a knowledge of the habits and life history of the insect concerned. Both these fields of work involve insect physiology which is in many respects a new subject. The first comprehensive book on the subject was published by Wigglesworth (16)[3] in 1939.

The physiology of the insect cell is similar to the mammalian, but the physiology of organs and organ systems may be vastly different. There are wide physiological differences among the thousands of insect species, and so far only a few kinds have been studied extensively. Insect habits are better known than insect physiology, but there has been too great a tendency to interpret them in terms of what a man would do under the same circumstances. Such interpretations may or may not be correct.

THE LOCATION OF PLANTS FOR FOOD OR OVIPOSITION

Food plants are located by insects through their various sensory organs and in this way they show a preference for certain plants. As a whole the senses of an insect appear to be less well developed than they are in man. But certain senses may be far more acute than in any mammal. Generally, senses and reactions of an individual insect species vary within narrow limits unless changed by mutation. Behavior in insects can rarely be modified by experience. Three or four senses are concerned in finding food. These are sight, the chemical senses of smell and taste, and touch.

The compound eyes of insects are very different from the mammalian eye and the structure is well known (14). In range of color vision many insects "see" ultraviolet light and are blind to red; some can distinguish between different wave lengths, but what they see may not be the same as the colors we see. Butterflies and showy flowers differ in their ability to reflect ultraviolet rays, but whether crop varieties differ in this regard is apparently unrecorded. Leaf-feeding insects in general are attracted to the color green, but the reverse has been noted in some cases. Red-leafed cotton has been reported (5) to be more resistant to the boll weevil than at least some

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[3]Figures in parenthesis refer to "Literature Cited", p. 732.

of the green-leafed varieties. Celery varieties with green leaves and stems have been observed (7) to be more resistant to the tarnished plant bug than varieties with yellow color. The yellow-green varieties of peas are more resistant to the pea aphid than the blue green varieties (11). In some or all of these the relationship may be with some physiological character of the plant associated with color.

The finding of food plants by insects is usually associated with the chemical senses, taste and smell, in which some volatile constituents of the plant are involved. Organs for the reception of odors are known to occur on various parts of the insect body, but are most common on the antennae where they may act as "direction finders" in contrast to the single location of the olfactory organ of mammals.

The reaction to odors does not include a wide variety in any individual species of insect, but in the case of those substances to which the sense organs are attuned the perception may be remarkably acute. Often single substances or groups of related ones are concerned. The Japanese beetle responds to geraniol, a substance found in geraniums and other plants on which the Japanese beetle feeds, and to related substances present in favored food plants. The cabbage butterfly is attracted to mustard oil found in its favored food plants among the Brassicaceae.

Plant breeders have produced cabbage and marigolds without their distinctive odor, thus indicating the possibilities of the production of plant varieties unattractive to insects. The preference of corn ear worm for oviposition on silks of sweet corn rather than field corn probably is an olfactory response.

There is some evidence that insects, such as some grasshoppers, distinguish food plants through the sense of taste. There is clear evidence that some insects may react to concentrations of sugar or other chemicals that are too low for human perception. Some organs of taste may be located about the insect mouth, but they have also been demonstrated to be present on the tarsi of the front feet.

Plants for food or oviposition are sometimes selected by insects largely through a sense of touch. In the extensive feeding and starvation tests made before cactus insects were introduced for the control of prickly pear in Australia, it was found that physical similarity was most often the factor governing the feeding of an insect on a species of plant new to it. Botanical relationships and chemical likenesses were of less importance (2). *Euaresta aequalis*, a fly breeding in cockle bur seeds, will attempt oviposition in an imitation bur but does not appear to be attracted by the, to us, obvious cockle bur odor, although this insect is rarely found far from its food plant. The relation of smooth and pubescent plant varieties to insect population has often been observed in resistance studies. In some cases, as cotton, red clover, and soybeans, at least, the effect of the pubescence comes through oviposition reactions rather than through food relationships.

The food-finding and egg-laying impulses in insects are typically chains of stimuli and reflexes which are conditioned not only by the internal physiology of the individual but also by external conditions of moisture, temperature, sunlight, etc., as well as food. Breaks in

this chain at any point may result in lower oviposition and may or may not be related to resistance.

The egg-laying apparatus of an insect varies from relatively simple tubes to complex structures used for inserting eggs into woody stems. Sense organs of various kinds, especially those concerned with touch and the chemical senses, are found on these structures. Such sense organs are concerned in the final actions of an insect toward the food plant for its larva.

FOODS AND FEEDING OF INSECTS

When insects feed on resistant plants, there frequently follows various adverse effects on the insect fecundity and life history. These effects, called *antibiosis* (8, 9), apparently arise primarily from some interference with feeding or the lack of necessary food substances.

The essential problem among the plant-feeding insects is to get through the cell wall of the plant so that the contents may be digested. Insects solve this problem by the mechanical breaking up, by piercing of the cells, and by the action of enzymes through the cell wall. Enzymes capable of digesting cellulose have rarely, if ever, been found in insects feeding on plants.

The plant cells of particles of leaves, taken in by some insects with chewing mouth parts, appear to pass unchanged through the digestive system unless the cells are broken open. In other insects the cell contents appear to be extracted through the unbroken cell wall.

The food requirements of insects for growth and reproduction differ greatly among different species, but include, in addition to carbohydrates and proteins, certain elements, especially phosphorus and potassium and certain of the vitamins or vitamin-like substances. The absence or inaccessibility of any of these substances may be related to resistance.

Insects feeding on plants have mouth parts of either the chewing or the piercing-sucking types. The mandibles of the chewing insects are of a great variety of patterns and are sometimes adapted to special uses correlated with the plant structure to be attacked. Some caterpillars feed at the edge of a leaf, others normally on the surface; some use only the upper surface of the leaf, others only the lower. Connected with the mandibles of these insects is a large muscle attached broadly to the exoskeleton making possible considerable pressure at the cutting edge of the jaw. The power of such muscles is shown by the ease with which some insects tunnel through the hardest wood. Hardness of plant tissue has frequently been cited as a "cause" of resistance to various insects. Later research has sometimes shown that physiological relationships were of greater importance.

A consideration of insect structures and abilities leads one to question whether differences in hardness of tissue of the order of those occurring between varieties of a plant species is sufficient to explain many of the cases of resistance. For instance, during the grasshopper outbreaks of 1934 the grasshoppers near Manhattan ate much of the corn, chewed the bark off certain trees, and the labels off the stakes in the experimental sorghum nurseries, but only nibbled at the

sorghum leaves. Certainly a difference in hardness of tissue did not explain these choices and still less would such an explanation be probable in the case of differences found in amount of injury among different corn hybrids and varieties.

Differential toughness of pericarp has been cited as one cause for differences in extent of injury by corn ear worm to young corn kernels. In Kansas later generations of this insect tunnel through the hardened kernels and here also differential injury is shown by various hybrids. Those with softer, starchy kernels and also the hard flinty types occur both among hybrids with low and with high degree of injury by corn ear worm. Evidently, hardness of kernel is not a deciding factor in late injury by corn ear worm. It is still less likely to be a factor when the kernels are in the milk or dough stage.

Among the insects with piercing and sucking mouthparts, the mandibles and maxillae are formed into four needle-like stylets held within a jointed beak. The inner surfaces of the maxillae are grooved and when pressed together form two canals connected with muscular pumps in the head. Through one of these channels salivary fluid is forced into the plant; through the other plant fluids, which sometimes may be partially digested, are drawn back into the insect. These stylets are inserted into the plant by pushing first one and then the other forward while the base is held within the beak. Among some of the Hemiptera, such as the chinch bug, the stylets are thrust *through* the cells; among many of the other insects, including a majority of the aphids, the setal path is *between* the cells. Some species of insects employ both methods. Around the stylets within the plant there is formed a stylet sheath apparently coming mostly from the insect salivary glands. The punctures of these insects usually reach the phloem tissue, although in other species of insects, even some species belonging to the same genus (*Empoasca*), the required food comes from mesophyll tissue only. In the case of the sugar beet leaf hopper (3), the stylets are apparently guided to the phloem tissue by a hydrogen-ion gradient which tends to be more acid near the epidermis and more alkaline near the phloem.

Again in this connection the statement sometimes made that hardness of tissue is often a cause of resistance to sucking insects is open to question. Some of these insects normally feed on or send their stylets through or between cells of branches of trees where lignification is heavier than in most crop plants. The mechanism of piercing of these species of insects is not known to differ from related species feeding in softer tissue. It appears doubtful, for instance, if differences in thickness of epidermis to be found between the leaves of two varieties of a crop plant would be enough to encourage an aphid to feed on one and prevent it from feeding on the other. Differences in plant structure may be found, however, to be genetically linked with resistance and hence prove to be useful marks in searching for resistance.

The effects of the feeding of chewing insects is usually only too apparent, but the effects of the feeding of sucking insects may not be so easily measured. Sometimes little damage is done and large numbers of insects must be present before damage by aphids, for example,

can be measured. A part, often the principal cause of injury, is in clogging of conducting vessels of the plant by stylet sheath material. Some insects, notably the tarnished plant bug and its relatives, inject toxic fluid into the plant, resulting in considerable breakdown of cells and swelling or holes, especially where the injury takes place in a bud. It should also be remembered that some of these sucking insects are first-class transmitters of plant disease and that it may be possible in some cases to confuse resistance to insects with resistance to a plant disease carried by the insect.

The thrips (Thysanoptera) contain another group of plant feeders with sucking mouthparts that differ in many details from the aphids and other true bugs. In these minute insects the lower part of the head is drawn out into a cone containing three piercing stylets. A hole is made by the mandible through a single cell of the epidermis of the plant. Only a few cells near the point of puncture of the epidermis can be reached by the stylets and from these cells the plant fluids are drawn up by the insect. There is no clear evidence of any injection of salivary fluid. Considering the anatomical evidence, it appears possible that in this case a differential thickness of the wall of epidermal cells may be of importance in resistance. Cases where this appeared to be true have been reported (6) in onions.

DIFFERENCE BETWEEN SPECIES AND WITHIN SPECIES OF INSECTS

Each species of insect must be considered separately in studies of insect resistance. This is not always easy to do under field conditions. Immature stages of insects frequently cannot be identified except after rearing to the adult stage. The larvae and pupae of the southwestern corn borer cannot be distinguished from the southern cornstalk borer, yet the two insects appear to be very different in their potential destructiveness to the corn crop. The abundant leafhoppers of the genus *Empoasca*, some of which cause hopperburn of potatoes and alfalfa yellows, are distinguishable largely on the basis of internal male sex organs or genitalia, yet different species of this genus are very different in their food habits and destructiveness to food plants (12).

The fact that a plant variety is resistant to one species of aphid is by no means evidence that it will be resistant to other aphids. This has been amply demonstrated (17) in the case of the aphids of raspberry where varieties resistant to *Amphorophora rubi* Kalt. have not been resistant to the other species of aphids feeding on raspberry. The assumption that varieties resistant to one species of insect will also be resistant to a related insect has sometimes been made and may be responsible for errors in results reported in the literature on insect resistance.

Related to this problem is that of the presence of biotypes of insects within a single species and differing in food habit. These biotypes may be responsible for differences in results when resistant varieties are tested in various regions. Perhaps because of the newness of any widespread testing of varieties for insect resistance only a few such

cases have been studied, but the presence of biotypes must be taken into consideration. The not infrequent occurrence of insect biotypes has been reported (4, 15). Such biotypes within species may be of two general kinds, *viz.*, a mutant form attuned to a particular feature of the environment or groups of individuals inherently vigorous and able to survive various kinds of adverse conditions. Distinction must be made between inherent biotypes and variations resulting from degree of infestation and the effect of environmental conditions either on host plant or insect.

HABITS AND LIFE HISTORY IN RELATION TO RESISTANCE

One of the difficult phases of insect resistance studies has been the production of consecutive satisfactory insect populations in test plots. This sometimes involves opposite considerations from those that usually motivate the economic entomologist. Continuous studies involve either taking the plant varieties to the insect, or bringing the insect to the plants in the laboratory, greenhouse, or restricted field tests. Each of these methods should have its place in any insect resistance program, for while intensive laboratory methods may not reveal the economic possibilities of lower degrees of resistance, field studies may not reveal escapes, differences in degrees of resistance, and other sources of error which should be known to the investigator. These studies need detailed knowledge and sometimes research on the habits and life history of the insect being used. Of course, it is the particular problem of entomologists to produce satisfactory infestations. This may not mean the largest possible populations, but rather controlled populations. Because resistance is so often relative, various intensities of infestation are needed. For plant breeding work that infestation is best which gives the maximum difference between the resistant and the susceptible parents. For testing of new varieties the widest range likely to be available under farm conditions is necessary. Advantage should be taken of insect outbreaks in securing data on resistance.

Differential or changing abundance of insects, coupled with the fact that resistance is relative, may complicate genetic interpretation, especially when based on percentages of plants killed or similar criteria. This has been suggested in the case of chinch bug resistance in sorghum (13) and again in the case of resistance of Marquillo wheat hybrids to Hessian fly (10). In the segregating population of sorghums reported, a count of F_3 lines made on July 13 appeared to indicate that resistance was dominant. A classification made 11 days later appeared to indicate that resistance was recessive. During these 11 days the chinch bugs had been feeding and increasing in numbers and size. This perhaps resulted in considerable injury to individual plants heterozgous for resistance. A similar apparent partial shift in dominance as related to intensity of infestation has been noted in various Marquillo wheat hybrids tested for Hessian fly resistance during different seasons and in different places.

The handling of test materials requires a synchronization of insect life history with suitable stages in the life history of the plant. Since

the corn ear worm is attracted to corn silk for oviposition, corn hybrids being tested for resistance to this insect ordinarily should be planted at a time when they will come in silk during the period of maximum egg laying of this insect. Adjustments in planting date to offset differences in inherent maturities, where possible, are preferable to statistical adjustments. Hand infestations of individual plants and individual plant and insect life history records are time-consuming and limit the total number of strains which may be studied, but under certain conditions they are necessary and have frequently given valuable information. The stage in the insect life history to be used in manual infestations must be dictated by a knowledge of that insect.

The result of insect resistance studies are sometimes influenced by the fact that the insect uses a part of the food plant for shelter during feeding. The relation of loose or tight sorghum leaf sheaths to chinch bug resistance has been pointed out (13). The leaves of most varieties of onions fit closely together near the base and this area is a favorite feeding place for the onion thrips. The onion variety White Persian has leaves which do not fit so closely together and there is experimental evidence (6) that this growth habit is one factor in the resistance of that variety. The long tight husks of corn ears have frequently been mentioned in connection with resistance to corn ear worm and Barber (1) has shown that this is brought about because the cannibalistic tendencies of the larvae are allowed full play in the confined shelter of the husks. Thus, various tropisms of insects must receive considerable attention in resistance studies.

SUMMARY

A number of facts in the relation of insect habits and physiology to the resistance of plants to insect attack have been discussed. Others could have been mentioned. In studies of insect resistance one or more of the relationships discussed will be found of importance. In spite of the complexity of some of the problems much progress has already been made in the breeding of plants that are resistant to insects. For further progress it will often be necessary to give increasing attention to the intimate details of insect and plant biology and genetics.

The great number of insects and the endless variety of their adaptations to plant life complicate the difficulties in drawing conclusions about the relationship of insect physiology to the causes of resistance. Yet recent studies (9) have shown the importance of three insect-plant relations in many cases of insect resistance. These are tolerance in the plants and preference and antibiosis in the insects. The latter term refers to any adverse effect on the insect resulting frequently from the use of resistant plants as food. Studies of both preference and antibiosis involve a knowledge of insect physiology and habits.

A knowledge of insect physiology, tropisms, and life history is necessary in any extended breeding program for resistance to insects. Such information will aid in the search for and understanding of the causes of resistance. Without such knowledge one may be more easily misled in respect to type of insect damage, presence of plants that

escape infestation, the correct interpretation of experiments, and statistical analyses. Information on insect life history is needed in the planning of infestations of controlled intensities. The correct identification of the insect, including possible biological races, should receive adequate attention.

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NOTES

ABNORMAL LEAF FORMATION ON FLAX SEEDLINGS CAUSED BY SPERGON[1]

ABNORMAL leaves on flax seedlings grown from seed treated with "Spergon" were first observed in nursery plantings[2] made at Pullman, Washington, in the spring of 1942. Bison and Redwing flax were treated with 2 ounces of Spergon per bushel and seeded on April 6. On May 10, approximately 80% of the seedlings showed abnormal leaves. Seedlings made in the same manner on April 18 and 20 had approximately 30% seedlings with abnormal leaves.

The abnormality consisted of apparent lateral fusion of two to six leaves at the same node as shown in Fig. 1. Such fusion occurred in

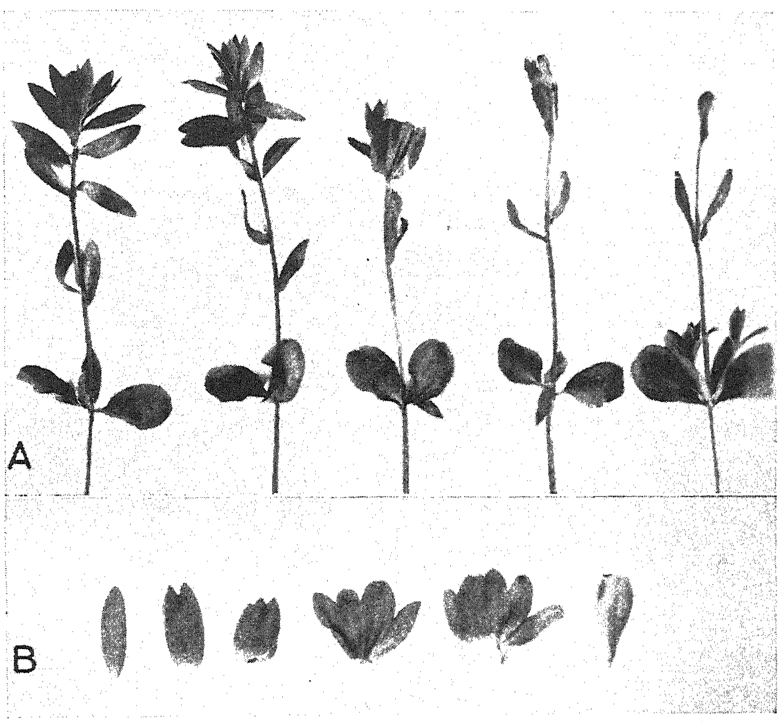

FIG. 1.—A, flax seedlings showing, from left to right, normal leaves, a double leaf, a large abnormal leaf, a tubular leaf, and a tubular leaf enclosing an injured apical bud as indicated by the lateral shoot development at the cotyledons. B, flax leaves showing varying degrees of fusion in abnormal leaves.

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[1]Published as Scientific Paper No. 557, College of Agriculture and Agricultural Experiment Station, State College of Washington, Pullman, Wash.

[2]Field observations were taken from plantings made by O. A. Vogel, Associate Agronomist, Bureau of Plant Industry, U. S. Dept. of Agriculture.

varying degrees. The most extreme case was a leaf which formed a complete tube around the stem with the apical bud inside. In some cases the number of lobes on the tube gave little indication of the number of leaves involved in the abnormal development. In other seedlings the lobes were quite distinct with some very deep clefts extending almost to the stem. In the majority of instances a tube was not formed, but one or more large leaves with two to six lobes occurred. Abnormalities usually were found from the fifth to tenth leaves above the cotyledons. This agrees with the work of Crooks[3] who noted occasional double leaves occurring naturally within this region of the flax seedling.

Redwing flax seed treated with Spergon at different rates was seeded in the greenhouse April 17, 1943. Data taken on May 5 corroborated those from previous tests made with five other varieties and are shown in Table 1. As the rate of treatment increased, the frequency and degree of abnormality in the leaves also increased. Likewise, with an increase in Spergon application fewer normal leaves were produced between the cotyledons and the first abnormal leaf. It also was observed that there was greater elongation of the first internodes in those seedlings which exhibited a marked abnormality or definite injury. The first internode is normally less than 1 mm long, but in an occasional plant from seed treated at the rate of more than 3.6 ounces of Spergon per bushel, the first leaf was tube shaped and the internode was 15 to 20 mm long.

FIG. 2.—The tops of three flax plants showing abnormal leaves produced by application of Spergon to apical buds of seedlings. Left to right, normal leaves, large abnormal leaves, and a tubular leaf.

A small quantity of Spergon was applied directly to the apical buds of 2-week-old flax seedlings to determine the effect it might have on the plants. No effect was apparent for 2 weeks during which time the plants grew an additional 6 to 8 inches in height. At this point abnormal leaves, similar to the ones produced on the young seedlings, appeared as shown in Fig. 2.

The plants in the field on which abnormal leaves occurred grew adjacent to plants grown from seed treated with "New Improved Ceresan" and untreated seed in connection with seed treatment tests designed to determine control

[3]CROOKS, DONALD N. Histological and regenerative studies on the flax seedling. Bot. Gaz., 95:209–239. 1933.

TABLE 1.—*Summary of data taken in greenhouse on abnormal leaf development on flax seedlings grown from seed treated at different rates with Spergon.*

Spergon treatment, oz. per bu.	Total number of plants	Number of plants with abnormal leaves		Percentage of plants with abnormal leaves	Location of abnormal leaves on seedling (counting leaves above cotyledons)
		Double leaves	Larger leaves		
None......	84	1	0	1	6
0.6........	122	10	1	9	7 to 10 (12)*
1.2........	148	12	4	11	6 to 10
1.8........	135	17	10	20	5 to 9
2.4........	170	19	29	28	5 to 10
3.6........	196	31	52	42	5 to 9 (14)
Excess....	101	9	59	67	1 to 7

*Figures in parentheses represent one seedling.

measures for pre-emergence damping-off and seed decay resulting from cracked seed coats. Abnormal leaves were found only on the seedlings from Spergon-treated seed. At first there was a distinct difference in appearance between the rows having abnormal seedlings and rows from the other two treatments. This difference in appearence soon was outgrown and there was no further effect on the plants as far as subsequent growth or yield were concerned.

In view of the work of Crooks in his ontogenetic study of the flax leaf, it is suggested that Spergon strengthened the tendency of the apical primordia of some seedlings to differentiate leaf primordia in groups of two to six instead of singly. The action of the Spergon seemed to be limited to the primordial cells of the stem tip. Those tissues which already had been differentiated to some extent continued development. Spergon applied so that it could reach the apical primordium in an excessive amount apparently prevented further differentiation of leaf or stem primordial cells on the main shoot. New stems soon developed from lateral buds (Fig. 1 A).

These experiments were made with machine-threshed seed which was observed under magnification to have small cracks or open breaks in the seed coats of 65 to 75% of the seed. These seed coat injuries would provide an avenue of entrance by which the Spergon could reach the epicotyl in sufficient concentration to cause abnormal leaf development before the seed coat which held the Spergon was sloughed off in the process of emergence from the soil. This might explain the wide variation in the response of different seedlings in the same rate of treatment.—DWIGHT D. FORSYTH, *Seed Analyst, Department of Agronomy, State College of Washington, and* MAX L. SCHUSTER, *Research Fellow, Division of Plant Pathology, Washington Agricultural Experiment Station, Pullman, Wash.*

BARLEY VARIETIES RESISTANT TO STRIPE, *HELMINTHOSPORIUM GRAMINEUM* RABH.

INFORMATION on varietal resistance to this important barley disease, and on an easy method for appraising such resistance, seems timely in view of the current importance of increased production and the conservation of mercury and copper dusts now used for its control. The technic for obtaining infection is a round-about method resorted to only because no effective, simple, seed inoculation method is known. It involves use of male-sterile plants on which the wide-open flowers on entire spikes are dusted with spores immediately following mass pollination.[1] Since the male-sterile stock is very susceptible to stripe, resistance of the pollen parent may express itself in the progeny. Preliminary results, as shown in Table 1, suggest three genetic groupings of varieties based on the performance of their F_1 progeny, *viz.*, (1) resistant, with dominance nearly complete; (2) intermediate resistance or incomplete dominance; and (3) susceptible or dominance of susceptibility.

TABLE 1.—*Comparative resistance of certain barley varieties to a single culture of the stripe fungus as determined by their F_1 progeny responses.*

Pollen parent	C.I. No.	Infection in F_1 progeny of crosses with male sterile plants			
		1942		1943	
		Number of plants grown	Diseased plants, %	Number of plants grown	Diseased plants, %
Vaughn	1367	121	4.5	101	4.1
Hannchen	531	32	28.1	41	4.9
Wisconsin Barbless	5105	—	—	75	5.3
Arivat	6573	—	—	49	8.2
Trebi	936	9	33.3	119	24.4
Coast (Winter Tenn.)	4633	—	—	41	39.1
Hero	4602	—	—	24	50.0
Atlas	4118	31	41.9	27	55.6
Rojo	5401	—	—	76	63.2
Comp. Cross sel.	5368*	—	—	157	72.0
Colsess V	5987	14	78.6	8	75.0
California Mariout	1455	—	—	36	80.5
Club Mariout	261	—	—	37	81.1
Manchuria	2947	—	—	22	95.5

*Fertile prototype of male sterile.

In the experiments herein reported, susceptibility in plants first became evident 5 weeks before heading and in no case did these plants produce viable seeds. The stripe culture used for these tests traces to spores from a single plant. The groupings mentioned above have confirmation in earlier California tests involving fewer varieties in

[1] SUNESON, C. A., and HOUSTON, B. R. Male-sterile barley for study of floral infection. Phytopath., 32:431–432. 1942.

which infections were obtained by sprouting seeds on a media base supporting mycelial growth or by growing the varieties under conditions favorable for natural infection. In these early tests resistant Vaughn never showed more than 5% stripe; the less resistant Coast (Winter Tennessee) never more than 15%; and Atlas a universal susceptible reaction. If these earlier tests are reliable, California Mariout is resistant, but susceptibility is completely dominant when crossed with male-sterile. On the other hand, the difference in reaction may be due to a difference in strains of the inoculum, since the inoculum in the present tests is not known to be identical with that used earlier. In the North Central states, Dickson[2] lists Wisconsin Barbless and Trebi among the most resistant varieties grown.

From the results at hand it seems reasonably certain that the varieties Vaughn, Arivat, Wisconsin Barbless, Trebi, Coast (Winter Tennessee), and Hannchen are sufficiently resistant to stripe to permit their wartime cultivation without seed treatment, if the proper dusts are not available. Exclusive of Wisconsin Barbless, these varieties are now grown on about 1,000,000 acres in California and bordering states.—COIT A. SUNESON and SYLVIA C. SANTONI, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Department of Agronomy, University of California, cooperating.*

[2]DICKSON, J. G. Outline of Diseases of Cereal and Forage Crop Plants. Burgess Pub. Co. 1939.

BOOK REVIEW

THE CHEMICAL FORMULARY

H. Bennett, Editor-in-Chief. Brooklyn: Chemical Publishing Company. Vol. VI. XVIII+636 pages. 1943. $6.

THE thousands of recipes and formulas given in the present volume are all new and complement admirably the contents of previous volumes. After a general discussion of the art of compounding, the chapters deal with adhesives, beverages, cosmetics and drugs, emulsions, farm and garden specialties, food products, hides, leather and fur, inks and marking materials, lubricants and oils, materials of construction, metals and alloys, paints, varnishes, laquer and other coatings, paper, photography, polishes and abrasives, pyrotechnics and explosives, rubber, resins, plastics and waxes, soaps and cleaners, textiles and fibers, and miscellaneous formulas.

The list of substitute materials, various tabulated information and the 47 pages of indexes make this volume practically a handbook. The up-to-date character of most information is a tribute to the editor and his collaborators. No doubt, the Formulary is slowly becoming a "must" for technical libraries and no one concerned with science or technology will deny the usefulness of these volumes.—(Z. I. K.)

AGRONOMIC AFFAIRS

ROADSIDE MARKERS

ACTING upon a suggestion made by D. Howard Doane at the meeting of the Soil Science Society in St. Louis last fall, President Firman E. Bear has named a committee on roadside markers to consider ways and means of placing markers at conspicuous points along highways to locate important soil types. The committee is as follows: E. D. Fowler, *Chairman*, T. M. Bushnell, M. G. Cline, G. W. Conrey, H. J. Harper, J. R. Henderson, W. M. Johnson, R. J. Muckenhirn, S. S. Obenshain, R. S. Smith, R. E. Storie, and M. B. Sturgis.

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THE CAGE METHOD FOR DETERMINING CONSUMPTION AND YIELD OF PASTURE HERBAGE[1]

DAYTON L. KLINGMAN, S. R. MILES, AND G. O. MOTT[2]

NUMEROUS investigators in pasture research are using cages as a means of measuring the *production* of pasture herbage. A few are using the method to determine the *consumption* of pasture herbage by livestock. Some investigators have considered the method very inadequate and have not adopted it or have discarded it after a short trial. In experiments in Indiana, cages have been used for several years to measure production and consumption of pasture herbage. The data obtained have been very helpful in interpreting the gains in weight made by sheep and beef cattle and the milk production of dairy cows when grazing on various types of pasture.

Variations in the cage method have received considerable study at the Purdue University Agricultural Experiment Station during the past two years.

The purpose of the work reported here was to compare the precision resulting from a random choice with that from a selected choice of the second of the two areas to be clipped for estimating consumption by the difference method.[3] The use of duplicate cages and differences among operators were also investigated.

Vinall[4] states that it is desirable to measure the production of grazed plots by mowing representative areas protected from grazing. He says also, "There are two methods of arriving at yields. One attempts to measure the herbage consumed by the grazing animals; the other measures the annual growth of herbage, or that available for grazing."

The first method assumes that the difference in yield between a protected and a nearby grazed area is equal to the herbage consumed. The protected area is relocated at the beginning of each grazing

[1]Journal Paper No. 87, Purdue University Agricultural Experiment Station, Lafayette, Ind. Contribution from the Department of Agronomy. Received for publication March 6, 1943.

[2]Graduate Assistant, Associate in Agronomy, and Associate in Pasture Research, respectively. Based on data presented by the senior author in partial fulfilment of the requirements for the degree of master of science, May 1942.

[3]FUELLEMAN, R. P., and BURLISON, W. L. Pasture yields and consumption under grazing conditions. Jour. Amer. Soc. Agron., 31:399–412. 1939.

[4]VINALL, H. N. Pasture research. Jour. Amer. Soc. Agron., 26:1027–1030. 1934.

period. In the second method, the annual growth or production is the total yield obtained by clipping the same protected area throughout the season. The difference method of measuring consumption may have certain advantages over the above-described method of measuring the annual growth in that for the difference method the growth conditions of the grass within the cage more nearly represent those of the grass under actual grazing conditions. In connection with the difference method it is possible, also, to calculate the herbage available for any grazing period and the season's production. The season's production is equal to the season's herbage consumption plus the aftermath remaining at the end of the grazing season.

EXPERIMENTAL PROCEDURE

The field work for this study was all done on July 11, 1941, in a 12-acre permanent pasture at the experimental livestock farm located north of West Lafayette, Ind. At that time, the pasture had been grazed by 14 beef cows since the last of April. Although the pasture had been heavily stocked, small patches of Kentucky bluegrass and timothy were left ungrazed. The closely grazed portions contained considerably more white clover and Canada bluegrass than the lightly grazed portions. No botanical analysis was made of the herbage.

Four workers—two experienced and two inexperienced, working independently—performed the experiment after receiving careful instructions as to procedure.

The cages used in pasture experiments at this station protect an area 4 by 4 feet. Any area of this size is referred to in this paper as a *unit*. Each "caged" unit was located at *random* by tossing a short stake and was designated as a C unit (C for caged). No cages were actually placed, however. Two "uncaged" units were next chosen within 6 to 15 feet of the caged unit. One of these was *selected* as being *similar* to the C unit in plant composition, amount of growth, and soil characteristics, while the other was chosen at random. The *similar* unit was called an S unit (S for similar) and the *random* uncaged unit was designated as an R unit (R for random).

A local area, which in this study was sampled by a set of three units (one each of C, S, and R), is designated as a *station*. Since there were 80 stations well distributed over the 12-acre pasture, the stations averaged 0.15 acre in size and about 80 feet from "center" to "center". Each of the four operators harvested 20 stations (60 units) scattered over the entire pasture.

The three units of a station were harvested immediately after selection. The operators clipped the herbage as close to the ground as possible with Wiss grass shears, weighed it, and took a moisture sample promptly upon harvest.

In this paper, *yield* means the weight of dry matter in the herbage clipped from either a caged or an uncaged area, while *production* is the yield from a caged area at the end of a grazing period, a grazing period being the number of days from the time a cage is placed until it is removed and the herbage under it is cut. In other words, *production* is the amount of dry matter which would have been available to livestock during the period if there had been no cage. Since, in this technic study, harvesting followed immediately the choosing of the units, the length of the grazing period was zero and *production* is properly estimated from R as well as from C units, both of which were chosen at random. *Consumption* is the yield of a caged unit minus the yield of the companion uncaged unit. All yield, production, and consumption figures are stated as pounds of dry matter per acre.

RESULTS

SIMILAR VERSUS RANDOM UNITS

Since there was no grazing in this pasture between the selection and the harvesting, the consumption is known to be zero. Each difference between a C and its R unit or between a C and its S unit is therefore entirely an error in the estimate of zero consumption. The standard deviation of the errors is 378 pounds per acre when the R units were used but only 134 pounds when the S units were used. Every one of the four operators was able to reduce the experimental error greatly by selection.

When estimates of consumption are actually being made there are two sources of error. One is the fact that grazing is not uniform, while the second is the variation in soil and herbage between the caged and the uncaged units at the beginning of the period for which consumption is estimated. The error due to the first source is uncontrollable, but the results indicated above show that men can considerably reduce the error due to the second source by selecting the second unit similar to the first—the first having been chosen at random. This selection must be made when the cage is placed and the location of the uncaged unit must be marked or recorded in such a manner that it can be definitely identified at the end of the grazing period. If the place is marked, care must be used that the marking will have no effect on the grazing.

The variance (square of the standard deviation) of the errors in the estimates of consumption using R units is 7.96 times that using S units. This indicates a very highly significant difference. At first thought this fact might lead to the conclusion that, for equal precision, 8 times as many cages would be needed if both of the units needed to estimate consumption were chosen at random as if only one were chosen at random and the second were selected. This is not the case, however, because increasing the number of cages decreases the error due to nonuniform grazing as well as that due to differences between the caged and the uncaged units. From this research no definite estimate can be made as to the relative numbers of cages needed with the two methods. However, it is true that, for equal precision, the method of selection requires fewer cages than the method of random choice of both units; or, in other words, an equal number of cages will give more reliable estimates of consumption with the selection method.

A study is now under way to estimate the relative number of cages needed for the two methods to attain equal precision.

NUMBER OF CAGES

Some researchers have used "duplicate" cages in estimating production or consumption. This means placing cages in pairs with the members of pairs rather close together but the pairs well distributed over the pasture. A study was made of the precision of production estimates with cages placed singly, in pairs, and in trios.

To measure production, all units should be located at random, which was the case for the C and R units. The data from only these

two kinds of units were used in this part of the study. A C and its R unit averaged about 10 feet apart, while pairs (station "centers") averaged about 80 feet apart. From the production data, the variation was estimated for *between units within stations*, for *among stations*, and for *among operators*. The analysis of variance is given in Table 1. It is seen that the variation among stations is significantly greater than that between units. From the variances (mean squares), estimates can be made of the number of cages needed to obtain a chosen precision when the cages are placed singly, in pairs, or in trios.

TABLE 1.—*Analysis of variance for production.*

Variation	Degrees of freedom	Mean square	F
Total	159	——	——
Among operators	3	1,273,642	4.07**
Among stations of same operator	76	313,172	4.40**
Between units within stations	80	71,244	——

**Significant at the 1% level.

To make such estimates let

V_u = the variance of units within stations

V_s = the net variance for stations—the variance for units and operators having been excluded

k = the number of units per station

n = the number of stations

N = nk = the total number of units (or cages—since every unit is caged in production estimation)

t = standard measure, (t = 2, approximately, at the 5% level of probability)

E = the error to be tolerated at the chosen level of probability. For example, if we choose E as 100 pounds per acre at the 5% level, we wish only 5% of the mean estimates of production (if many estimates were made) to deviate as much as 100 pounds from the true production.

Now let us make estimates of the true values of V_u and V_s, using data from Table 1. The estimate of V_u is 71,244. kV_s+V_u = the variance among stations in Table 1. Substituting, $2V_s+71{,}244=313{,}172$ and $V_s=120{,}964$.

Using these estimates, we next estimate the number of cages for chosen values of E by means of the formulas

$$n=\frac{t^2}{E^2}\left(V_s+\frac{V_u}{k}\right), \text{ and } N=nk.$$

For E = 100, t = 2 (the 5% level), and one cage at a place (k = 1),

$$n=\frac{4}{10{,}000}(120{,}964+71{,}244)=77, \text{ and}$$

$$N=nk=(77)\,(1)=77.$$

For the same values of E and t and for cages in trios (k=3),

$$n=\frac{4}{10,000}\left(120,964+\frac{71,244}{3}\right)=58, \text{ and}$$

$$N=nk=(58)\ (3)=174.$$

Similar calculations gave the numbers in Table 2. This table gives the estimated number of cages needed to attain selected degrees of precision, in estimating production, when cages are placed 1, 2, or 3 at a station.

It is noted from Table 2 that, to estimate the production of a pasture, the most efficient use of *cages* is to place them singly; furthermore, this is certainly advisable since the time and cost per cage is about the same regardless of whether the cages are placed singly or in groups. With trios it is necessary to use 2.26 times as many and with pairs 1.63 times as many as with single cages. If the researcher wished to use only about 20 cages, the expected error at the 5% level is approximately 200 pounds per acre with single cages, 250 pounds with pairs, and 300 pounds with trios.

Table 2 applies strictly only to pastures with the same station-to-station and unit-to-unit variability as this pasture. However, the principle holds universally that the most efficient method is to place cages singly for production or consumption estimates, so long as the cost per cage is the same regardless of whether the cages are grouped.

TABLE 2.—*Number of cages necessary to measure production of the pasture in this study with a desired precision at the 5% level of probability, using one, two, or three cages per station.*

Precision desired*	Cages placed		
	Singly	In pairs	In trios
50	308	502	696
100	77	126	174
150	34	56	78
200	19	32	45
250	12	20	30
300	9	14	21
400	5	8	12
500	3	6	9

*Precision is in pounds of dry matter per acre. See E in the list of symbols for further explanation.

Let us now consider the number of stations to sample in order to attain a desired precision after it has been decided how many cages to place per station. Column 2 of Table 2 gives such figures for cages placed singly. For calculating these numbers it was assumed that the station-to-station variance would remain constant regardless of the number of stations sampled. This assumption must usually be made for such computations, although it does not always hold. As the number of stations sampled increases they are necessarily closer together in any given pasture and the variation among them may decrease. In fact, if the stations are so numerous that they are very

close, their variance is almost certain to be less than if they are far apart. In that case the calculated number is excessive. If most of the area of a pasture were taken in the samples, the precision of the estimate would be much greater than the calculation, based on the aforementioned assumption, would indicate. In the limiting case in which so many "samples" are taken that the entire pasture is harvested, there is no *sampling* error in the *yield* of that pasture and it is determined with perfect precision, except for errors due to such causes as imperfect weighing and failure to cut and collect all the herbage.

Considerations such as those of the last paragraph have a bearing on the comparative numbers of cages needed in large and small pastures for estimating either production or consumption. If the station-to-station variability for the entire pasture is equal for both a large and a small pasture, the same number of cages is needed for each in order to attain equal precision. But with a considerable increase in the number of stations, the precision would likely increase more rapidly in the smaller pasture because the station-to-station variation would probably decrease faster in it. In this study it was found that the variability was only slightly greater for the entire 12-acre pasture than for much smaller areas in it. It is concluded that if the pasture had been only 2 acres in size, say, practically as many cages would have been necessary as for the entire 12 acres for equal precision in measuring production. Experience in Indiana indicates that this is not an infrequent occurrence.

DIFFERENCES AMONG OPERATORS

It is of some importance to compare the results of different individuals doing the sampling in order to know whether it is satisfactory to use more than one operator and whether the results of different men are comparable.

Table 1 shows that operators differed very significantly in their estimates of production. Table 3 gives these estimates. The differences between operators were due to differences in the heights at which the herbage was cut. Operator A (experienced) noticed that operator C (inexperienced) was not clipping the grass nearly close enough to the ground when they both had about one-half of their areas clipped. He instructed operator C to continue clipping in the same manner, however, so the data would be consistent—consistently low. This fact accounts entirely for the differences among operators. This is shown by a more detailed analysis than that in Table 1. This detailed analysis showed that A, B, and D differed less among themselves than would be expected, judging by the experimental error, but that operator C's production estimate was very significantly lower than the average of the yields of the other three. Because of this bias, the production estimates of operator C were not included in the averages in the last line of Table 3.

A consistent under-estimate of production would be serious if the true production were of importance, but if it is desired only to compare the production in different pastures or plots, under-estimates would probably be unimportant, provided clipping was at the same

height in all pastures and was low enough to get some of every blade of grass, because the differences between pastures would probably be affected only very slightly.

TABLE 3.—*A comparison of the estimates of production and of consumption made by four persons based on pounds of dry matter per acre.*

Operator	Production estimates			Consumption estimates*			
				Using R units		Using S units	
	Using C units	Using R units	Average	Consumption*	Significant difference†	Consumption*	Significant difference†
A........	601	526	563	75	171	19	56
B........	660	809	734	−149	221	4	67
C........	343	376	359	− 33	105	33	33
D........	716	753	734	− 37	189	− 5	87
Average..	—	—	—	74	—	15	—
Av. for A, B, D...	659	696	677	—	—	—	—

*The true consumption is known to be zero in this experiment.
†At the 5% level.

Table 3 also gives information concerning estimates of consumption, which is known to be zero. When the R units were used in estimating consumption, no operator obtained an estimate which even approached a significant deviation from the true value. However, the errors of estimation were rather large. They varied from 33 to 149 pounds and averaged 74 pounds, disregarding algebraic signs. On the other hand, when the S units were used, the errors were small. They varied from 4 to 33 pounds and averaged 15 pounds. The largest error by this method was the same size as the smallest when the uncaged units were chosen at random. These facts reemphasize the greater accuracy of the method in which one of the two units needed to estimate consumption is selected similar to the other which is first chosen at random.

Turning to a consideration of the consumption estimates made by the use of the S units, it is noted that the estimates of three operators, namely, A, B, and D, did not approach a significant deviation from the true consumption of zero. It will be remembered that the same was true for all four operators when using R units. However, when using S units the estimate of operator C, was significantly in error. Further evidence that his estimate was biased in a positive direction is the fact that only 3 of his 20 estimates were negative. There is little doubt that in his selection of an S unit similar to a C unit he tended rather consistently to select an S unit lower in yield than the C unit. To avoid bias in the mean estimate due to such a tendency, an operator should select a unit at random and its mate to be similar, then by tossing a coin should decide which unit is to be caged. In this study the yield of the S unit was always subtracted from that of the C unit.

It is assumed that small errors of estimate for an operator are due to his clipping different units at a uniform height. It was very interesting to find from the data that operator C was significantly more consistent in his height of clipping of all three kinds of units than any other operator. In other words, his errors of estimate were smaller whether using an R unit or an S unit along with the corresponding C unit to estimate consumption. This fact was surprising because he was inexperienced and because he clipped rather high. Contrary to what was found, it would seem that a person who clips high could not clip at as uniform a height as one who clips as close to the ground as possible. Another point of interest brought out by the work of operator C is that the ability to clip at a uniform height may be independent of skill in selecting one unit similar to another. Operator A, who was experienced, was second most accurate in clipping at a uniform height.

Since men vary in their work, all operators should work in each pasture if treatments are not replicated. If treatments are replicated, each man may handle a replicate. Either of these procedures avoids bias due to confounding operator with treatment.

The differences among operators need cause no apprehension concerning the value of results when several workers must be used, so long as those workers make a sincere effort to follow instructions. The workers must be used properly, however.

SUMMARY

A study of certain phases of pasture research methods using cages has led to the following conclusions:

1. For estimating consumption by the difference method, it is more efficient to choose one unit at random and the second similar to the first than to choose both at random. After the two units are chosen, a coin should be tossed to decide which unit to cage. Each of four operators increased precision considerably by selection of the second unit.
2. It is more efficient to place cages singly than in groups.
3. For pastures with equal station-to-station variability, the same number of cages is needed for equal precision in estimating the production or consumption of the entire pasture, regardless of the size of the pasture. In the pasture studied, nearly as many cages would be needed for a 2-acre area as for the entire 12 acres.
4. It was found that men differ in their work, but the differences need cause no apprehension concerning the value of results when several workers must be used so long as those workers make a sincere effort to follow instructions. The workers must be used properly, however. Some suggestions are made regarding the use of workers.

FERTILIZER PLACEMENT STUDIES ON HILLSDALE SANDY LOAM SOIL[1]

A. G. WEIDEMANN[2]

DURING the last decade there has been an ever-increasing interest in the problem of how best to apply fertilizers to obtain maximum crop response and the most economic returns for the money spent. To supply answers to these questions, a rotation experiment was started on the farm of Michigan State College, East Lansing, Mich., in 1931, which involved the placement of a 2–12–6 fertilizer for corn and wheat in various locations with reference to the seed. Use was also made of stable manure, both alone and reinforced with superphosphate. Later there were added to the experiment comparisons of 2–12–6 with 0–12–6 fertilizer, and of a heavy application of phosphate and potash plowed under for corn with the same amounts of these elements plus 500 pounds of calcium cyanamide.

The rotation consisted of corn, barley, wheat, and clover. Pickett's yellow dent, an adapted, open-pollinated variety of corn was used. The clover sod was spring plowed for corn and the barley ground was plowed for wheat. The seedbed for barley was prepared by disking.

The experiment was conducted on Hillsdale sandy loam, a soil type which occupies large areas in south central and southwestern Michigan. Although this soil type is characterized by the presence of calcareous rocks of various sizes scattered throughout the profile, the soil itself is generally too acid to grow alfalfa or clover well. On the experimental field this condition was corrected by the application of liming material.

REVIEW OF LITERATURE

No attempt will be made to review the extensive literature dealing with the placement of fertilizer for corn and the effect of fertilizer on the other crops grown in the rotation. However, few studies have come to the attention of the writer concerning methods of applying fertilizer for wheat. Reference is made to several experiments with corn which touch on points mentioned specifically in this study.

Salter and associates (4)[3] found that delayed applications of 2–12–6 beside the corn rows or hills were less effective in 1937 than applications made at planting time. However, in 1938 and 1939 the treatment which gave the largest increase in yield consisted of applying one-third of the fertilizer (150 pounds) at planting time, one-third at the first cultivation, and one-third at the time of last cultivation.

Miles (3) found that over a period of years small amounts of fertilizer applied near the seed gave better results with corn than fertilizer applied by other meth-

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[3]Figures in parenthesis refer to "Literature Cited", p. 766.

ods. Cook (1), on the other hand, obtained very satisfactory increases in yields of corn on several heavy soil types in Indiana by plowing under from 100 to 500 pounds of cyanamide and supplying phosphate and potash. Scarseth and associates (5) also report appreciable increases in yields of both grain and stover, when moisture supply was adequate, from plowing under varying quantities of sulfate of ammonia and drilling 0–12–12 or 3–12–12 fertilizer at planting time. Additional nitrogen applied as a side dressing was sometimes beneficial. The soils used were deficient in nitrogen.

Wiancko (6) and Williams (7) have pointed out that favorable growing conditions during the early part of the season are conducive to the development of suckers on corn, as is also increased soil fertility. In the case of drought in July and August, Williams opined that the yield of corn is likely to be decreased by suckers, unless they are removed. Dungan (2) found corn on fertile Illinois soils, which had produced many suckers, suffered severely in drought periods. When the leaves were removed early in the season from plants which had developed many suckers, the suckers fed the plant and enabled it to produce grain. He concluded that it would be better if plants did not produce suckers, but when they did develop, it was detrimental to the plant to remove them.

PLAN OF EXPERIMENT

The 88 plots in the experimental field were arranged in four blocks of 22 plots each, in order that each of the four crops in the rotation might be grown every year. The plots were 14 feet by 94 feet which is a convenient size as it will accommodate four rows of corn and two drill widths of small grain. Although the practice of randomizing replicated treatments in different blocks was in use when this experiment was started, its value was not so well recognized as it is at present, hence the older system of having every third plot a check or unfertilized plot without replication of the treatments was followed.

The plan was to apply the fertilizers for corn and wheat and allow the barley and clover to recover as much of the unused fertilizer as they could. There were exceptions to this general procedure, as will be noted in the list of fertilizer treatments. At the beginning of the experiment in 1931, 11 treatments were used with the intervening checks. The rest of the plots were reserved and used later as new ideas concerning fertilizer placement presented themselves.

All fertilizer application rates are given on the acre basis.

Fertilizer "drilled deep, solid" was drilled as deep as possible in 7-inch rows with the fertilizer attachment of a grain drill, previous to planting the seed.

The "in row" placement consisted of dropping the fertilizer near the seed with the attachment on a John Deere planter. In the case of wheat, "with seed" refers to application with a fertilizer attachment of a grain drill at seeding time.

The fertilizer was placed as deep as possible with the corn planter in the method described as "deep with planter before drilling seed," and then the seed was drilled at normal depth in the same rows.

Fertilizer "broadcast and plowed under" was broadcast by hand before plowing, and that "broadcast and worked in" was incorporated with the soil by use of a springtooth harrow after being broadcast by hand on plowed ground.

A fertilizer attachment for a John Deere cultivator was used to place the plant food about 4 inches from the row and behind the first cultivator tooth where it was covered with soil by the second tooth in the "side-dressed with cultivator" method. Fertilizer so placed at the first cultivation is not disturbed by subsequent cultivations farther from the row.

By mixing the fertilizer with a suitable quantity of soil it was possible to apply it by sprinkling 1 pound of the mixture in the bottom of the furrow each time the plow passed across the plot in the "in bottom of furrow" method.

Manure for the experiment was provided in the form of horse manure. The phosphate used to reinforce the manure was equivalent in amount to that contained in 300 pounds of 2–12–6 fertilizer. It was applied broadcast before plowing.

Corn was drilled in rows 42 inches apart with a John Deere Planter sufficiently thick so that it could be thinned to about three plants per 42 inches of row after danger from cutworms and birds was past. No injury to germination from fertilizer was observed.

Wheat and barley were drilled with a standard disk drill at the rate of 1.5 bushels per acre. Clover was drilled with a disk drill as early as one could get on the land in the spring. Manure and sulfate of ammonia top-dressings were applied immediately after the clover was seeded.

Small grains were harvested by cutting an area 10 drill rows wide and 85 feet long from the center of each plot, thus avoiding border effects. The corn from the two center rows of each plot was cut and shocked and allowed to stand for 3 to 4 weeks to dry. The shocks were then weighed and the ears husked and graded into sound, marketable ears and poor or immature ears. Each grade was weighed, the number of ears counted, and samples taken for moisture determination. Yields of stover were calculated on a field weight basis at husking time and of grain on room dry weights. The clover from 2 square rods was weighed when freshly cut and moisture samples taken. Yields are reported on the air-dry basis.

RESULTS

As the treatments were not replicated, differences in yields due to treatments were calculated by reference to a curve constructed from the yields of check plots. The portion of the curve connecting the points derived from the yields of the nearest check plots was assumed to indicate what the yield of a plot would have been had it been untreated. The yield data are presented in Table 1, and in Table 2 are given the values of the increased yields, the cost of the fertilizers, and the net gains.

RESULTS WITH CLOVER

The Hillsdale sandy loam does not have a high water-retaining capacity and, as a result, clover seedings in wheat are frequently thin and occasionally fail. When moisture is a limiting factor, fertilizer applications have little value in establishing stands of clover. When a stand is obtained, however, the fertilizer is beneficial to growth as is evidenced by an increased yield for all fertilized plots. The outstanding fact in connection with the clover yields is the large response to manure applications whether they be plowed under for the wheat or applied as an early spring top-dressing. The reasons for this beneficial affect of manure are doubtless due to the fact that clover received no direct fertilization during the hay-producing year and the residual effect of the manure was greater than that of the commercial fertilizer. It is remarkable that the 5-ton top-dressing gave as large yields as the 10 tons plowed under for corn and wheat. This effect may be largely accounted for by the fact that the top-dressing proved highly beneficial in the establishment of seedings. When the clover seeding

TABLE 1.—*Effect of different fertilizers and different fertilizer placement methods on the yield of corn, barley, wheat, and clover.*

Plot No.	Treatment		Corn, 11-year av.				Barley, 10-year av.				Wheat, 10-year av.				Clover hay, 10-year av.*	
			Grain, bu.†		Stover, lbs.		Grain, bu.		Straw, lbs.		Grain, bu.		Straw, lbs.			
	For corn	For wheat	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield, lbs.	Increase over check, lbs.
1	300 lbs. 2–12–6 drilled deep, solid	300 lbs. 2–12–6 drilled deep, solid	38.34	2.94	3,750	625	22.93	4.33	1,293	143	30.58	4.38	2,531	421	2,245	515
3	300 lbs. 2–12–6 broadcast and plowed under	300 lbs. 2–12–6 broadcast and plowed under	39.00	2.10	3,553	403	22.85	4.25	1,239	169	28.54	4.14	2,204	184	2,159	184
4	200 lbs. 2–12–6 drilled deep, solid 100 lbs. 2–12–6 in row	200 lbs. 2–12–6 drilled deep, solid; 100 lbs. 2–12–6 with seed	41.42	3.52	3,898	698	23.16	4.41	1,272	212	31.88	8.48	2,634	654	2,441	271
6	300 lbs. 2–12–6 deep with planter before drilling seed	300 lbs. 2–12–6 with seed; top-dressed in spring with 60 lbs. $(NH_4)_2SO_4$	44.90	5.70	4,219	879	25.38	5.48	1,384	244	35.58	11.78	3,133	1,073	2,495	275

7	None	300 lbs. 2–12–6 with seed; top-dressed in spring with 5 tons manure	45.90	6.80	3,819	399	27.95	7.05	1,543	323	39.74	14.94	3,865	1,685	3,117	1,042
9	300 lbs. 2–12–6 in row	300 lbs. 2–12–6 drilled with seed	40.94	2.44	4,313	913	24.25	3.65	1,374	134	32.62	7.82	2,755	565	2,447	497
10	300 lbs. 2–12–6 broadcast and worked in	300 lbs. 2–12–6 broadcast and worked in	42.69	4.49	3,861	561	25.01	5.71	1,375	215	30.09	6.59	2,595	595	2,415	485
12	300 lbs. 2–12–6 side-dressed with cultivator	150 lbs. 4–24–12 drilled with seed	37.73	0.83	4,025	775	25.73	6.33	1,401	251	30.41	7.91	2,519	569	2,254	334
13	10 tons manure and 300 lbs. 0–12–0 plowed under	10 tons manure and 300 lbs. 0–12–0 plowed under	39.81	3.51	5,104	1,774	38.02	18.02	2,143	973	40.74	17.74	3,743	1,783	2,969	1,049
15	10 tons manure plowed under	10 tons manure plowed under	38.07	2.07	5,069	1,619	38.08	18.28	2,115	965	38.54	15.04	3,593	1,623	2,839	939
16	300 lbs. 2–12–6 in bottom of furrow	300 lbs. 2–12–6 in bottom of furrow	35.85	-0.55	4,148	673	24.63	5.33	1,257	167	28.87	5.37	2,318	348	2,129	229

*There was no clover in 1935, 1937, and 1940 due to failure of seedings the preceding years. The averages given here are for seven harvests divided by 10.
†70 pounds of ears taken to equal a bushel in all corn yield calculations.

TABLE 2.—*Economic returns per rotation due to the use of fertilizers and methods of fertilizer placement.*

Plot No.	Treatment		Value of increase per rotation*								Cost of fertilizer†	Net gain
			Corn		Barley		Wheat		Clover hay	Total		
	For corn	For wheat	Grain	Stover	Grain	Straw	Grain	Straw				
1	300 lbs. 2–12–6 drilled deep, solid	300 lbs. 2–12–6 drilled deep, solid	$1.79	$0.94	$2.34	$0.21	$3.29	$0.63	$2.31	$11.51	$8.40	$3.11
3	300 lbs. 2–12–6 broadcast and plowed under	300 lbs. 2–12–6 broadcast and plowed under	1.28	0.60	2.30	0.25	3.11	0.28	0.82	8.64	8.40	0.24
4	200 lbs. 2–12–6 drilled deep, solid; 100 lbs. 2–12–6 in row	200 lbs. 2–12–6 drilled deep, solid; 100 lbs. 2–12–6 with seed	2.15	1.05	2.38	0.32	6.36	0.98	1.21	14.45	8.40	6.05
6	300 lbs. 2–12–6 deep with planter before drilling seed	300 lbs. 2–12–6 with seed; top-dressed in spring with 60 lbs. $(NH_4)_2SO_4$	3.48	1.32	2.96	0.37	8.84	1.61	1.23	19.81	9.53	10.28
7	None	300 lbs. 2–12–6 with seed; top-dressed in spring with 5 tons manure	4.15	0.60	3.81	0.48	11.21	2.53	4.67	27.45	11.70	15.75
9	300 lbs. 2–12–6 in row	300 lbs. 2–12–6 drilled with seed	1.49	1.37	1.97	0.20	5.87	0.85	2.23	13.98	8.40	5.58

10	300 lbs. 2–12–6 broadcast and worked in	300 lbs. 2–12–6 broadcast and worked in	2.74	0.84	3.08	0.32	4.94	0.89	2.17	14.98	8.40	6.58
12	300 lbs. 2–12–6 sidedressed with cultivator	150 lbs. 4–24–12 drilled with seed	0.51	1.16	3.42	0.38	5.93	0.85	1.50	13.75	8.03	5.72
13	10 tons manure and 300 lbs. 0–12–0 plowed under	10 tons manure and 300 lbs. 0–12–0 plowed under	2.14	2.66	9.73	1.46	13.31	2.67	4.70	36.67	34.21	2.46
15	10 tons manure plowed under	10 tons manure plowed under	1.26	2.43	9.87	1.45	11.28	2.43	4.21	32.93	30.00	2.93
16	300 lbs. 2–12–6 in bottom of furrow	300 lbs. 2–12–6 in bottom of furrow	−0.34	1.01	2.88	0.25	4.03	0.52	1.03	9.38	8.40	0.98
18	350 lbs. 0–20–0 and 200 lbs. 0–0–50 broadcast, disced in, and plowed under; 125 lbs. 2–12–6 in the row	None	0.13	2.43	6.55	0.60	2.21	0.26	2.27	14.45	10.25	4.20
19	350 lbs. 0–20–0, 200 lbs. 0–0–50, and 500 lbs. $CaCN_2$ broadcast, disced in, and plowed under; 125 lbs. 2–12–6 in the row	None	−1.55	2.82	8.82	1.05	5.45	0.88	3.25	20.72	19.13	1.59

*Values based on increases given in Tables 1 and 4.

Manure at \$1.50 per ton
2–12–6 at \$27.94 per ton
$(NH_4)_2SO_4$ at \$37.78 per ton
4–24–12 at \$51.00 per ton

0–20–0 at \$23.40 per ton
0–0–50 at \$44.10 per ton
$CaCN_2$ at \$35.50 per ton

Corn at \$0.61 per bu.
Wheat at \$0.75 per bu.
Barley at \$0.54 per bu.

Clover hay at \$8.95 per ton
Straw at \$3.00 per ton
Stover at \$3.00 per ton

†Fertilizer costs based on average retail price for duration of period used in the experiment.
Grain prices are 10-year average prices furnished by government agricultural statitician's office, Lansing, Michigan. Straw, stover, and manure prices estimated.

failed so there would be no hay crop, it was reseeded in the spring in order that there would be a green manuring crop to plow under for corn each year.

RESULTS WITH BARLEY

Barley yields varied considerably from year to year and, on the whole, are low, as the soil is not well adapted to barley production. Adverse weather conditions which delayed seeding and deficiency of moisture during the growth period are primarily responsible for the annual variations in yield. Differences in increases in yields resulting from fertilization are not appreciable except in those from the three plots receiving manure and from plots 12, 18, and 19, the latter two of which received a heavy application of fertilizer for corn (Table 4). It is noteworthy that the 10-ton manure applications plowed under were more effective than the 5-ton top-dressing. This was to be expected, as these two plots received four times as much manure during the rotation period as did plot 7 which received the top-dressing, and the growth of the barley was dependent on the residual fertility in the soil as it was not fertilized directly. No reason is evident for the above-average increase from plot 12.

RESULTS WITH WHEAT

As the wheat crop was fertilized directly, more response to applied fertilizer was to be expected than in the case of barley and clover. Yield increases varied from 4.14 to 17.74 bushels. Again, the largest increases were obtained from the plots treated with manure. Plowing under 10 tons of manure reinforced with 300 pounds of 0–12–0 gave the largest yield increase, followed by the manure application without the 0–12–0, and the 5-ton top-dressing with 300 pounds of 2–12–6 drilled with the seed which gave almost identical increases. Of the treatments consisting of commercial fertilizer only, those in which all or a part of the fertilizer was drilled with the seed were the most effective. Of the non-localized fertilizer applications, the placing of the fertilizer deep in the soil by plowing it under or by drilling it deep were not so effective as keeping it near the seed by broadcasting and working it into the surface soil. The value of nitrogen in the early spring is evidenced by the large increase from plot 6, which received the top-dressing of sulfate of ammonia. As might be expected, the spring application of available nitrogen was detrimental rather than beneficial to the clover seeded in the wheat.

RESULTS WITH CORN

It is noteworthy that all fertilizer applications increased the yield of corn grain with the exception of that in which the fertilizer was placed at the bottom of the furrow (Fig. 1). In the case of 6 of the 11 treatments, the increase was less than 3 bushels to the acre. Furthermore, quite frequently a fertilized plot yielded less than the adjoining untreated plot for a given year. A decrease in yield (–0.55 bushel) occurred when the fertilizer was placed in the bottom of the furrow, a method which might be expected to prove beneficial since the

FIG. 1.—Effect of fertilizer vs. no fertilizer for corn in 1939. Left, check; right, 300 pounds of 2–12–6 below seed in row. This condition is typical for these treatments in early summer. Yield, left, 30.82 bushels corn and 2,986 pounds stover per acre; right, 29.15 bushels corn and 3,547 pounds stover per acre. These same treatments in 1938 produced the following results: Left, 52.67 bushels corn and 3,920 pounds stover; right 57.04 bushels corn and 5,410 pounds stover per acre.

nutrients were in moist soil a larger proportion of the time than were those placed nearer the soil surface. The largest yield increase (6.80 bushels) was obtained from the plot which received 300 pounds of fertilizer for wheat with 5 tons of manure applied as a spring top-dressing but no fertilizer for corn. A 10-ton application of manure plowed under gave the small increase of 2.07 bushels in corn grain, and supplementing the manure with 300 pounds of 0–12–0 resulted in only 1.44 bushels further increase. Side dressing with a cultivator proved a very unsatisfactory method of applying fertilizer to corn.

Applications of manure and of fertilizer placed near the seed stimulated the early growth of the corn and materially increased the yields of stover (Fig. 2). Methods of placement which put the nutrients near the seed were especially effective in increasing early growth and plowing under manure resulted in the greatest increases in stover

FIG. 2.—Effect of row fertilization vs. broadcast fertilization for corn in 1939. Left, 300 pounds of 2–12–6 in the row; right, 300 pounds of 2–12–6 broadcast. This is typical of these treatments in early summer. Yield, left, 27.88 bushels of corn and 3,263 pounds stover; right, 35.23 bushels corn and 3,249 pounds stover. These same treatments in 1938 produced the following results: Left, 59.62 bushels corn and 5,061 pounds stover; right, 60.86 bushels corn and 4,484 pounds stover.

yields. Of especial interest is the fact that the smallest increase in yield of stover accompanied the greatest increase in yield of grain. Surprisingly, however, the next to the smallest increase in stover was obtained from the plot that gave a very small (2.10 bushels) increase in grain. Evidently there was no consistent correlation between stover yields and grain yields.

Because of the lack of correlation between early growth and grain yield and between yields of stover and grain, some additional fertilizer treatments were added. It was thought that omission of the nitrogen from the fertilizer might result in less early growth of the plants and still increase the yield. The average results from 300 pounds of fertilizer with and without nitrogen drilled in the row for corn and wheat are given in Table 3. The data show no appreciable difference in yield of corn grain or stover as a result of omitting the nitrogen.

Another thought was that a small amount of fertilizer might stimulate the production of larger plants which did not produce a correspondingly large amount of grain because of an insufficient supply of nutrients in the latter part of the growing season. Accordingly, a fertilizer application consisting of 500 pounds of calcium cyanamide, 350 pounds of 0–20–0, and 200 pounds of 0–0–50 was broadcast and plowed under, and 125 pounds of 2–12–6 were drilled with the corn seed. An adjoining plot received the same treatment with the omission of the calcium cyanamide. No fertilizer was applied for wheat on these plots.

The results (Table 4) show a decrease of 2.54 bushels of corn for the plot receiving the complete treatment and no appreciable increase for the treatment without the cyanamide. Stover yields were increased decidedly in each case. Yields of other crops in the rotation were increased, especially by the treatment including 500 pounds of cyanamide and particularly in the case of barley which followed the corn. The plot which received the cyanamide gave a wheat yield increase 2.46 times that from the plot which received the phosphate and potash without the extra nitrogen. The yield increase from the latter plot was no greater than might have been expected from the 125 pounds of 2–12–6 drilled with the seed.

Inasmuch as heavy applications of plant nutrients did not materially increase the yield of corn, a further study of the available data was made in an effort to determine why corn does not respond more favorably to fertilizer on this soil.

It is to be expected that quantity and distribution of rainfall would have a marked influence on the effect of fertilizer on grain yields. To study the part played by this factor in the present experiment, the results for the period of 1931 to 1934, inclusive, including two seasons of limited summer rainfall, are compared to those for a period of more satisfactory precipitation (1935 to 1941, inclusive) in Table 5. The rainfall data are presented in Table 6. The period included in the experiment was preceded by a year (1930) of very low rainfall which would tend to deplete the soil moisture supply. The critical period for corn in Michigan, so far as moisture supply is concerned, comes in the latter half of July and in August. This period was very dry in 1931.

TABLE 3.—*Effect of 0–12–6 and 2–12–6 fertilizers on the yield of corn, barley, wheat, and clover.*

Treatment for both corn and wheat	Corn, 8-year av.				Barley, 7 -ear av.				Wheat, 7-year av.				Clover hay, 6-year av.*	
	Grain, bu.		Stover, lbs.		Grain, bu.		Straw, lbs.		Grain, bu.		Straw, lbs.			
	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield, lbs.	Increase over check, lbs.
300 lbs. 0–12–6 drilled in row with corn.................. 300 lbs. 0–12–6 drilled with wheat	37.30	1.77	4,054	789	21.51	2.72	1,129	16	28.20	4.83	2,258	247	1,709	236
300 lbs. 2–12–6 drilled in row with corn.................. 300 lbs. 2–12–6 drilled with wheat	36.53	1.00	4,047	782	23.93	5.14	1,194	81	28.23	4.86	2,278	267	1,969	496

*Clover seedings failed two years. The averages given here are for four harvests divided by six.

TABLE 4.—*Effect of heavy fertilizer applications, including calcium cyanamide, on the yield of corn, barley, wheat, and clover.*

Plot No.	Treatment*	Corn, 6-year av.				Barley, 5-year av.				Wheat, 4-year av.				Clover hay; 3-year av.†	
		Grain, bu.		Stover, lbs.		Grain, bu.		Straw, lbs.		Grain, bu.		Straw, lbs.			
		Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield, lbs.	Increase over check, lbs.
18	350 lbs. 0-20-0 and 200 lbs. 0-0-50 broadcast, disced in, and plowed under + 125 lbs. 2-12-6 in the row	35.97	0.21	4,909	1,617	30.25	12.13	1,539	402	27.67	2.95	2,139	174	2,171	507
19	350 lbs. 0-20-0, 200 lbs. 0-0-50, and 500 lbs. $CaCN_2$ broadcast, disced in, and plowed under + 125 lbs. 2-12-6 in the row	33.15	−2.54	5,134	1,878	33.56	16.33	1,827	700	31.48	7.26	2,504	586	2,212	726

*Fertilizer was applied for corn only.
†There was no clover in 1940 due to failure of seedings in 1939. The averages given here are for two harvests divided by three.

In 1934 there was very little rain in July after July 6, and with the exception of the month of April, the critical period was preceded by several months of below-normal precipitation.

During the latter period (1935 to 1941, inclusive), 1936 was the most unfavorable year. The heaviest rainfall of that season was fairly well disbributed through the month of September which was too late to do the corn much good. While the July precipitation for 1937 to 1940, inclusive, was below normal, it was, in most cases, preceded and followed by months of sufficient rainfall.

During the period of adverse weather only 4 of the 11 treatments gave positive increases in yield, while during the favorable seasons all but one treatment gave positive increases. In seasons of low precipitation placing the fertilizer deep in the soil by plowing it under, and by putting it in the bottom of the furrow resulted in decreased yields, although these are methods of application which might be expected to prove beneficial in dry seasons. Placing the fertilizer under the furrow slice also gave a negative yield increase during the period of more favorable seasons. It is interesting to note that the treatment which gave the highest average increase during the period of more favorable rainfall involved applying no fertilizer for corn directly. The wheat was fertilized and also top-dressed with 5 tons of manure. This procedure evidently supplied sufficient nutrients for the corn, but did not stimulate excessive early growth. This was also the second best treatment in the more unfavorable period. Placing fertilizer deep with the planter before drilling the seed gave comparatively good results in both wet and dry seasons but required additional labor.

The year 1934 was a very poor corn year, while 1937 was an exceptionally favorable season. A study of the data for the latter year shows that corn will respond very satisfactory to fertilizer applications when climatic conditions throughout the growing season are favorable for the crop. Drilling the fertilizer near the seed is a very satisfactory method of application under such conditions as is also putting all the fertilizer on the wheat crop.

Although there is no consistent correlation between yields of stover and grain, there is reason for thinking that treatments which result in a large growth of stalk, particularly in the early summer, are not conducive to large yields of grain unless the latter part of the season is especially favorable. Some of the factors which contribute to these results are discussed below.

A record was kept of the number of suckers and number of ears produced on the two center rows of corn on each plot for a period of 8 years. These sucker counts are presented in Table 7, together with the average yields of grain for that period. The percentage of plants producing ears, the yields, and the weight of 100 ears of corn for the adverse year of 1934 and the favorable year of 1937 are also given. It is noticeable that there is a great difference in the number of suckers produced on each plot from year to year.

The exceptionally large number of suckers produced on all plots during the unfavorable year of 1934 was undoubtedly due to the favorable growth conditions during the early part of the season.

TABLE 5.—*Differences in average yields of corn between the periods of 1931–34 and 1935–41 and for 1934 and 1937 as affected by seasonal conditions.*

Plot No.	Treatment		Corn, yields bu.							
			1931 to 1934, inclusive		1935 to 1941, inclusive		1934		1937	
	For corn	For wheat	Acre yield	Increase over check*	Acre yield	Increase over check	Acre yield	Increase over check	Acre yield	Increase over check
1	300 lbs. 2–12–6 drilled deep, solid	300 lbs. 2–12–6 drilled deep, solid	28.41	−1.59	44.02	5.52	8.77	−4.03	62.87	9.12
3	300 lbs. 2–12–6 broadcast and plowed under	300 lbs. 2–12–6 broadcast and plowed under	28.77	−0.73	44.84	3.64	12.14	−0.66	61.00	7.25
4	200 lbs. 2–12–6 drilled deep, solid; 100 lbs. 2–12–6 in row	200 lbs. 2–12–6 drilled deep, solid; 100 lbs. 2–12–6 with seed	29.51	0.01	48.86	5.56	10.05	−2.95	70.08	16.43
6	300 lbs. 2–12–6 deep with planter before drilling seed	300 lbs. 2–12–6 with seed; top-dressed in spring with 60 lbs. $(NH_4)_2SO_4$	35.04	4.79	50.53	6.03	16.50	1.80	70.41	17.81

7	None	300 lbs. 2–12–6 with seed; top-dressed in spring with 5 tons manure	35.26	4.26	51.98	8.28	21.93	6.18	64.70	13.20
9	300 lbs. 2–12–6 in row	300 lbs. 2–12–6 drilled with seed	31.14	−2.06	46.54	4.84	15.31	−1.94	69.52	17.82
10	300 lbs. 2–12–6 broadcast and worked in	300 lbs. 2–12–6 broadcast and worked in	34.85	1.10	47.17	6.42	19.87	2.12	63.06	10.06
12	300 lbs. 2–12–6 side dressed with cultivator	150 lbs. 4–24–12 drilled with seed	31.31	−1.14	41.39	1.99	15.01	−3.89	61.72	5.92
13	10 tons manure and 300 lbs. 0–12–0 plowed under	10 tons manure and 300 lbs. 0–12–0 plowed under	29.64	−1.66	45.63	6.63	10.26	−9.14	65.62	9.12
15	10 tons manure plowed under	10 tons manure plowed under	31.04	−0.26	42.09	3.39	11.89	−7.61	64.27	8.97
16	300 lbs. 2–12–6 in bottom of furrow	300 lbs. 2–12–6 in bottom of furrow	31.71	−0.39	38.22	−0.63	10.04	−9.06	57.63	5.43

*The minus signs show that the treated plots yielded less than the check.

Observations during this study indicated that the quantity of available nutrients immediately surrounding the young plants has a greater influence on sucker production than does the general fertility level of the soil. The factors of weather and fertility which induce sucker production also tend to promote a heavy growth of foliage, which in case of a limited moisture supply later in the season may result in an increased barrenness of stalks and a general decrease in yield of grain.

TABLE 6.—*Precipitation in inches during the growing periods covering part of the duration of the experiment reported*.*

Year	Apr.	May	June	July	Aug.	Sept.	Total	Annual
1930	1.97	3.36	2.79	0.50	0.18	1.42	10.22	18.50
1931	1.87	3.71	3.73	0.92	1.70	3.33	15.26	28.63
1932	2.18	5.03	1.24	3.44	3.71	3.04	18.64	34.22
1933	3.35	3.95	2.56	1.43	2.14	5.37	18.80	31.66
1934	2.68	1.33	1.67	2.14	1.51	2.21	11.54	21.00
1935	1.60	3.88	4.95	2.60	2.69	2.49	18.21	31.28
1936	3.37	0.78	2.98	1.22	2.42	7.76	18.53	27.65
1937	6.33	3.43	6.77	1.64	4.42	1.28	23.87	33.60
1938	1.42	5.73	2.89	1.50	4.24	1.64	17.42	32.39
1939	4.21	2.07	3.77	1.60	1.97	1.41	15.03	27.18
1940	1.42	4.66	5.70	1.84	9.21	1.42	24.25	37.84
Normal	2.58	3.42	3.51	3.10	2.82	2.91	18.34	31.43

*These figures obtained from the U. S. Weather Bureau Station at East Lansing, Mich., where the experiment was conducted.

This statement is partly borne out by observations of increased barrenness of plants on fertilized plots in some years and partly by the figures in Table 7. These figures show a much larger number of suckers from given treatments in 1934 than in 1937. The yields of stover from given treatments for the two years are fairly comparable, although they, as well as the number of suckers, are larger on fertilized plots than on check plots. The yield of grain and percentage of ear-bearing plants, however, were low for 1934, with a tendency for yields to be lower on fertilized plots than on check plots. While the average results for 8 years show no consistent relationship between yield of grain and number of suckers produced, there is a tendency in given seasons toward a direct relationship between number of suckers and yield of stover and an inverse relationship between number of suckers and yield of grain. The development of normally dormant buds on the ear shanks, resulting in two or more ears on the same shank, is also stimulated by available nutrient elements near the plants. These multiple ears (Fig. 3) produce practically no kernels.

The yield of grain is affected by both the size of ears and the percentage of ear-bearing plants, either or both of which may be affected by fertilizer treatments. By inducing the development of large leafy plants larger ears will be produced in favorable years, and, on the other hand, smaller ears in unfavorable years because of the increased demand for soil moisture. Fertilizers may influence the percentage of

ear-bearing plants by bringing them to the ear-setting stage or to the pollination period at a time when conditions are unfavorable for these processes.

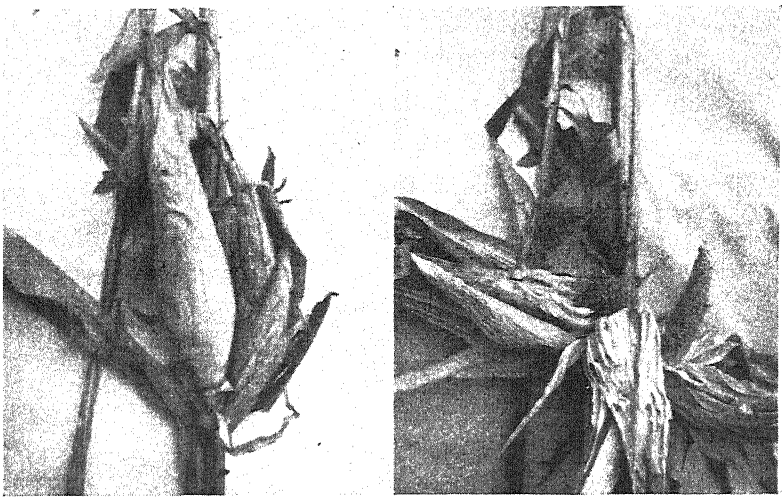

FIG. 3.—Multiple ears are often prevalent where rapid early growth takes place followed by hot dry weather in midsummer. This condition is usually associated with favorable weather conditions in the early part of the season and an abundance of readily available plant food, where manure is plowed under or commercial fertilizer placed in the row. Left, two rudimentary ears on the same shank. Right, same with husks stripped back. Note the absence of kernels.

SUMMARY AND CONCLUSIONS

A study was made of the effect on crop yields of applying 2-12-6 fertilizer by different methods to corn and wheat in a rotation of corn, barley, wheat, and clover grown on Hillsdale sandy loam soil. Some treatments also included manure, heavy applications of fertilizer plowed under for corn, and 0-12-6 fertilizer. Each crop was grown every year.

The increases in yield resulting from fertilization are probably greater than they would have been had the experiment been placed on a different field each year as the soil of the untreated or check plots became somewhat less productive as the years passed.

In an effort to explain the response of corn to different soil treatments, observations and records were made of the effects of seasonal conditions and of a combination of fertilizer treatment and seasonal conditions on crop growth and yield. Counts were made of the number of corn suckers produced per plot for a number of years and of the number of good and poor ears. Average weights of ears were determined and a relationship worked out between soil treatments, weather conditions, yields, size of ears, and percentage of ear-bearing stalks.

Although no fertilizer was applied directly for barley and clover, these crops showed noticeable responses to the residues of fertilizer

TABLE 7.—*Effect of fertilizer treatments and season on sucker production, yield of corn, percentage of ear-bearing plants, and weight per ear.*

Plot No.	Treatment for corn	Number of suckers per 180 feet of row										1934 crop					1937 crop				
		1934	1935	1936	1937	1938	1939	1940	1941	Av.	Av. yield, 1934–41, bu.	No. of suckers in 180 ft. of row	Acre yield: Stover, lbs.	Acre yield: Grain, bu.	Corn per 100 ears, lbs.	Ear-bearing plants, %*	No. of suckers in 180 ft. of row	Acre yield: Stover, lbs.	Acre yield: Grain, bu.	Corn per 100 ears, lbs.	Ear-bearing plants, %*
1	300 lbs. 2–12–6 drilled deep, solid	55	2	21	11	8	3	6	6	14	39.61	55	3,675	8.77	13.25	48.20	11	3,917	62.87	38.57	107.84
2	Check	29	0	16	3	3	0	0	2	6⅝	36.04	29	3,136	12.64	15.61	57.34	3	3,243	53.69	33.55	103.84
3	300 lbs. 2–12–6 broadcast and plowed under	17	0	10	1	8	2	8	2	6	40.75	17	3,682	12.14	12.94	62.91	1	3,886	61.00	39.34	100.00
4	200 lbs. 2–12–6 drilled deep solid; 100 lbs. 2–12–6 in row	34	8	25	15	10	6	1	16	14⅜	44.00	34	3,796	10.05	12.41	55.03	15	4,301	70.08	43.00	103.77
5	Check	21	2	7	2	6	0	0	4	5¼	40.67	21	3,751	13.51	13.03	67.74	2	3,284	53.29	35.26	102.00
6	300 lbs. 2–12–6 deep with planter before drilling seed	74	7	43	37	17	22	2	39	30⅛	46.27	74	4,660	16.50	15.91	70.95	37	4,553	70.41	40.97	115.23

7	None	26	0	14	5	9	0	0	6	7½	48.22	26	4,311	21.93	18.05	85.42	5	3,775	64.70	41.20	103.92
8	Check	18	1	10	2	1	2	0	2	4½	39.37	18	3,609	16.66	17.39	66.44	2	3,257	50.83	34.54	97.38
9	300 lbs. 2-12-6 in row	60	22	37	38	13	17	0	45	29	42.63	60	4,391	15.31	15.82	68.06	38	4,608	69.52	40.45	112.99
10	300 lbs. 2-12-6 broadcast and worked in	18	1	19	1	3	1	2	6	6⅜	43.75	18	3,820	19.87	19.16	75.54	1	3,834	63.06	40.93	104.00
11	Check	7	0	7	1	0	3	0	3	2⅝	37.23	7	3,277	18.17	16.43	76.19	1	3,194	54.30	35.47	100.65
12	300 lbs. 2-12-6 side dressed with cultivator	37	2	19	11	10	12	18	11	15	38.09	37	4,135	15.01	13.69	75.00	11	4,408	61.72	39.80	100.64
13	10 tons manure and 300 lbs. 0-12-0 plowed under	41	3	40	11	28	9	9	24	20⅝	41.20	41	5,085	10.26	12.83	59.56	11	5,289	65.62	42.86	99.36
14	Check	33	0	12	5	0	0	1	5	7	36.41	33	3,606	19.57	16.65	81.51	5	3,564	56.51	35.76	101.91
15	10 tons manure plowed under	26	3	47	5	27	5	3	16	16½	38.31	26	5,130	11.89	15.64	54.61	5	5,037	64.27	41.18	98.75
16	300 lbs. 2-12-6 in bottom of furrow	40	0	18	6	3	4	4	8	10⅜	34.69	40	4,923	10.04	13.03	52.35	6	4,124	57.63	37.89	100.65
17	Check	23	0	10	1	3	2	0	9	6	36.54	23	3,917	18.37	16.91	76.39	1	2,945	47.66	32.38	102.05

*Ratio of number of ears to number of plants per plot. Some plants were barren while others bore more than one ear.

applied to other crops in the rotation. Residues from manure applications produced the greatest increases in clover. Barley yields were materially increased by residues of manure and of heavy applications of commercial fertilizer. Seasonal conditions also greatly influenced the growth of clover and barley.

Manure plowed under resulted in the largest yields of wheat, followed by commercial fertilizer drilled with the seed supplemented with a spring topdressing of manure. Commercial fertilizer drilled with the wheat seed gave better results than that applied broadcast and worked into the soil or that plowed under. Superphosphate used as a reinforcement to manure gave some, but not outstanding, increase in wheat yields.

There was a very close relationship between yields of grain and straw in the case of wheat and barley, but no such relationship existed between yields of corn grain and stover. The largest increases in stover yields resulted from applications of manure and from heavy applications of commercial fertilizer, especially fertilizer containing excessive amounts of nitrogen. Moderate applications of fertilizer produced larger yield increases of stover when placed in or near the row than when broadcast or plowed under. The proportion of grain to stover was greatest in corn grown on plots receiving broadcast applications of fertilizer and on plots well fertilized for wheat but receiving no fertilizer for corn.

The largest average yield of corn grain was obtained from the plot receiving 300 pounds of 2–12–6 fertilizer for wheat and a spring topdressing of 5 tons of manure, with no fertilizer applied for corn. In favorable seasons all fertilizer treatments resulted in increased corn yields, but in unfavorable seasons fertilizer applications were of little and frequently of negative value. Considering the average increases for the 11-year period, the results show little benefit from fertilizer applied directly for corn.

Considering the rotation as a whole, there was a net financial gain from all fertilizer treatments. The frequent failure of corn to respond satisfactorily to fertilizer materially reduced the returns for the rotation.

The tendency for fertilizer to increase the early growth of corn and to stimulate the production of suckers resulted, in dry years, in smaller ears and a higher percentage of barren stalks. These effects appear to account for the lower yields of grain and higher stover yields on the fertilized plots than on those receiving no fertilizer in unfavorable seasons. From the results it appears that the best way to increase corn yields on this soil type is to fertilize other crops in the rotation rather heavily, making use of green manures or animal manure, and to let the corn draw on the stored fertility. A direct correlation was found between yield in bushels, on the one hand, and size of ear and percentage of ear-bearing plants, or a combination of these two factors, on the other.

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RESPONSE OF SOYBEANS TO EXPERIMENTAL DEFOLIATION[1]

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THE increasing livestock industry in the southeastern states has necessitated a cheap source of forage. Supplementary pastures are recognized by most livestock men as essential for the economical production of beef or dairy products. This is especially true in many of the well-drained, sandy soils where permanent pastures are not adequate. The acreage of soybeans utilized as a grazing crop has increased recently in North Carolina, Biloxi being the variety most often used for this purpose. The authors are not aware of any controlled experiments in which the management of the soybean as a grazing crop has been investigated. Cattle are usually turned on to the crop and allowed to consume most of the foliage within a few days. They are then removed and the crop is allowed to produce new leaves. Information is needed on the varietal response to the frequency and degree of defoliation, and it was the object of the work reported in this paper to measure such response in the Biloxi and Tokyo varieties.

Most defoliation studies on perennials have been concerned with the maintenance of organic root reserves adequate for initiating new growth the following growing season. Such reserves are not so essential in annuals. A photosynthetic area must be maintained, however, that will permit recovery within the single growing season.

Eldredge (2),[3] Dungan (1), Hume and Franzke (3), and Li and Liu (5) have shown that grain yields of corn and *Andropogon sorghum* vary inversely with the degree of defoliation and that the reduction becomes progressively less as the plants approach maturity. Leukel, *et al.* (4) reported that cutting Sudan grass four times after it had reached a height suitable for grazing prevented new top growth. In the case of the soybean, information is needed on the effect of defoliation on both the recovery of leaves and the ultimate seed yield.

MATERIALS AND METHODS

Biloxi and Tokyo soybean varieties were grown on a Congaree sandy loam at Raleigh, N. C., during the summer of 1940 for the purpose of studying the effect of defoliation on leaf, stem, and seed yield. All of the combinations of four degrees and three frequencies of defoliation were studied. The treatments were as follows:

1. The light defoliation treatment consisted in the removal of all but six

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[3]Figures in parenthesis refer to "Literature Cited", p. 778.

leaves per plant at 10-, 20-, or 30-day intervals throughout the growing season, with the terminal bud remaining on the plant.

2. The medium defoliation treatment consisted in the removal of all but three leaves per plant at 10-, 20-, or 30-day intervals, with the terminal bud remaining on the plant.

3. The medium-bud removed defoliation treatment was the same as the medium defoliation, except that the terminal bud was also removed by breaking out the top of the plant at the time of leaf removal.

4. The severe or heavy defoliation treatment consisted in the complete defoliation of each plant at the specified frequency intervals.

5. The check was not defoliated until the end of the growing season.

A split-plot experimental design was used in which the two varieties were treated as whole plots and the 13 defoliation treatments as subplots. Each subplot consisted of one row 18 feet in length. Ten replications were used.

Treatments at the 10-, 20-, and 30-day frequencies on both varieties were begun on July 2, 5, and 8, respectively, and were continued through September 3, 5, and 7, respectively. Leaves were removed individually by grasping the base of the leaflets between the thumb and forefinger and snapping them off at the point where they joined the petiole. It has been observed that grazing animals remove very little, if any, of the petiole.

Analysis of variance, as described by Snedecor (6), was used on all of the data. The means for each degree of defoliation at each frequency are given in the tables. The frequency means were computed by combining the different degrees of defoliation. Likewise, the means for the degrees of defoliation were computed by combining the different frequencies of defoliation. Odds of 99:1 were used throughout in determining levels of significance.

EXPERIMENTAL RESULTS

TOTAL WEIGHT OF LEAVES PRODUCED

The mean yields of leaves for the various treatment combinations are shown in Table 1. Yields from the check plot were not included because of the shedding of the leaves. These data show that the total leaf yield of the two varieties did not differ significantly and that

TABLE 1.—*Total dry weight of leaves in grams.*

Degree of defoliation	Biloxi				Tokyo			
	Frequency in days			Degree mean	Frequency in days			Degree mean
	10	20	30		10	20	30	
Severe	427	552	938	639	470	724	902	699
Medium bud removed	782	1,056	986	941	810	876	943	876
Medium	828	1,089	1,039	985	918	973	954	948
Light	855	817	803	825	894	843	696	811
Frequency mean	723	878	942	848	773	854	874	834

The least significant difference:
Between frequency means ... 73
Between degree means ... 84
Between degrees within any frequency ... 146

frequency of defoliation affected both varieties in a similar manner. The means of the 10-day defoliation treatments were significantly lower than the corresponding 20- and 30-day means. Although the 30-day value is numerically larger than the 20, the difference is not significant.

The general effect of the degree of defoliation is also similar on both varieties. The medium intensity resulted in significantly higher leaf productivity than either the light or severe treatments. Complete defoliation severely reduced the weight of leaves produced. The removal of the terminal bud effected a slight but non-significant reduction in the leaf yield of each variety.

The analysis of the data shows a highly significant interaction between the degree and frequency of defoliation. This means that the response of the plants to the various degrees of defoliation was different as the recovery interval varied. Severely defoliated plants produced maximum growth with a 30-day recovery period, while light defoliation permitted most leaf growth when plants were defoliated every 10 days. The medium degree of defoliation was most efficient when practiced every 20 days, although the differences between the 20- and 30-day intervals are not significant.

Considering the degree of defoliation at a particular frequency, the yield of leaves is greatest, with one exception, with the medium defoliation treatment. Light defoliation at 10-day intervals resulted in a slight but non-significant increase in the productivity of Biloxi plants. Light defoliation at 10- or 20-day intervals resulted in a greater weight of leaves than was produced by plants severely defoliated, but the reverse was true of the 30-day frequency.

The Tokyo variety was less affected by variation of the leaf area than the Biloxi. This is indicated by the larger number of treatment means which do not differ significantly.

SEASONAL PRODUCTIVITY

The seasonal distribution of the yield is equally as important for grazing management as the total weight of leaves produced. Seasonal data for the 10-, 20-, and 30-day frequencies are presented in Figs. 1, 2, and 3, respectively. As can be seen from these figures, the seasonal decline was greatest in the 10- and least rapid in the 30-day frequency. Medium or light defoliation every 10 days resulted in a fairly uniform Biloxi yield, but a definite peak was reached by the Tokyo on August 24.

The weight of leaves removed at the first and last harvest were approximately the same from the light and medium defoliations every 20 days; the last harvests were larger in case of the 30-day interval with the same degree of defoliation.

RECOVERY GROWTH

Since the weights of leaves removed at the initial harvest were not affected by the treatments, they do not give an indication of the plant response to defoliation. The growth which occurred following the initial treatments is designated as "recovery growth". Differences in

recovery growth made by Biloxi and Tokyo were not statistically significant as can be seen from the data in Table 2. In the case of the Biloxi, the frequency of defoliation affected the amount of recovery growth in the same manner as it affected the total weight of leaves. Yields of Tokyo recovery growth were not significantly different for the three cutting frequencies.

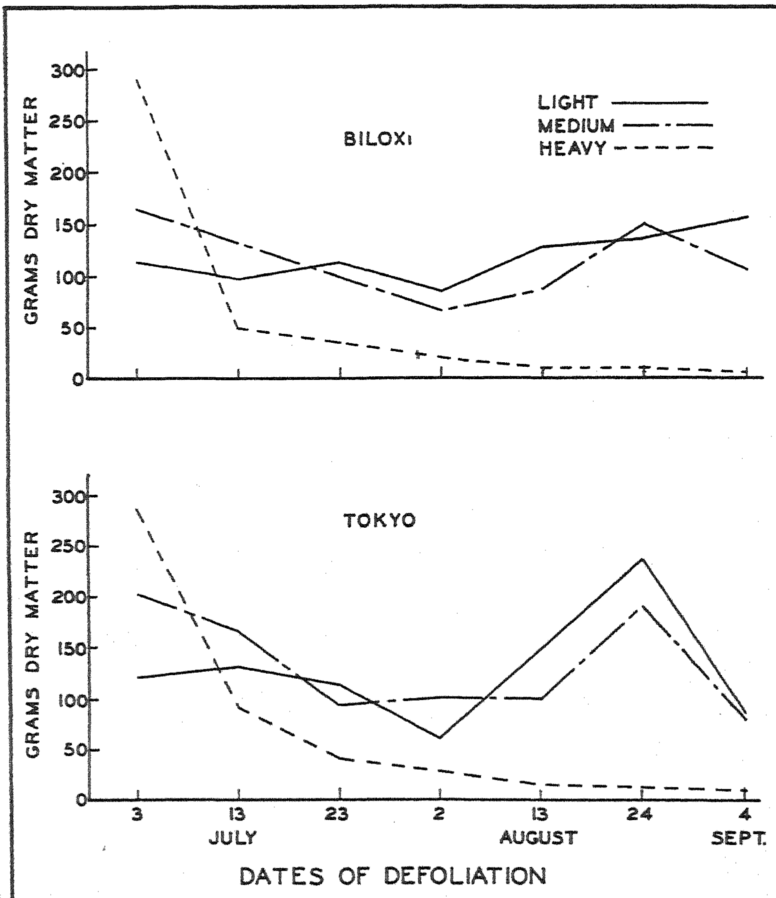

FIG. 1.—Dry weight of soybean leaves when defoliated at 10-day frequency. *Light*, removal of all but six leaves; *medium*, removal of all but three leaves; *heavy*, removal of all leaves throughout growing season.

The severe treatment resulted in significantly less recovery growth than any other degree of defoliation. Differences between light and medium defoliations were not significant, although the actual yields were larger when given the medium treatment. In the case of total yields, the medium defoliation differed significantly from the light.

TABLE 2.—*Dry weight of "recovery growth" of leaves in grams.*

Degree of defoliation	Biloxi				Tokyo			
	Frequency in days			Degree mean	Frequency in days			Degree mean
	10	20	30		10	20	30	
Severe	136	241	547	308	187	373	504	355
Medium bud removed	597	840	730	722	593	644	660	632
Medium	661	863	788	771	715	726	704	715
Light	742	708	650	700	776	706	536	673
Frequency mean	534	663	679	625	568	612	601	594

The least significant difference:
Between frequency means 68
Between degree means 79
Between degrees within any frequency 137

Recovery growth interaction between the degree and frequency of defoliation were also similar to the total weight. Light defoliation with a 30-day frequency resulted in lower recovery growth for both varieties. Medium defoliation at a 20- or 30-day frequency or light defoliation every 10 or 20 days was more favorable to the Biloxi. The severe treatment was not conducive to recovery for either variety.

WEIGHT OF STEMS AND ROOTS

Table 3 presents the treatment means for the dry weight of stems and roots produced. Biloxi is more productive than Tokyo. Biloxi weights increase significantly as the interval allowed for recovery varied from 10 to 20 and 30 days. The Tokyo means show the same trends, but the difference between the 10- and 20-day means was not greater than expected as a result of random variation.

TABLE 3.—*Dry weight of roots and stems in grams.*

Degree of defoliation	Biloxi				Tokyo			
	Frequency in days			Degree mean	Frequency in days			Degree mean
	10	20	30		10	20	30	
Severe	132	210	782	375	192	424	598	405
Medium bud removed	851	1,124	1,093	1,023	513	575	688	592
Medium	993	1,155	1,329	1,159	619	682	846	716
Light	1,264	1,293	1,641	1,399	838	827	1,015	893
Frequency mean	810	946	1,211	Check, 2,057	540	627	787	Check, 1,348

The least significant difference:
Between frequency means 111
Between degree means 128
Between degrees within any frequency 222

The severe, medium-bud removed, medium, and light defoliation means are all significantly different from each other. The weight of stems and roots produced increases consistently as the treatments become less severe. A similar trend is shown by the means of the 10-, 20-, and 30-day frequency treatments, but not all differences between means are significant.

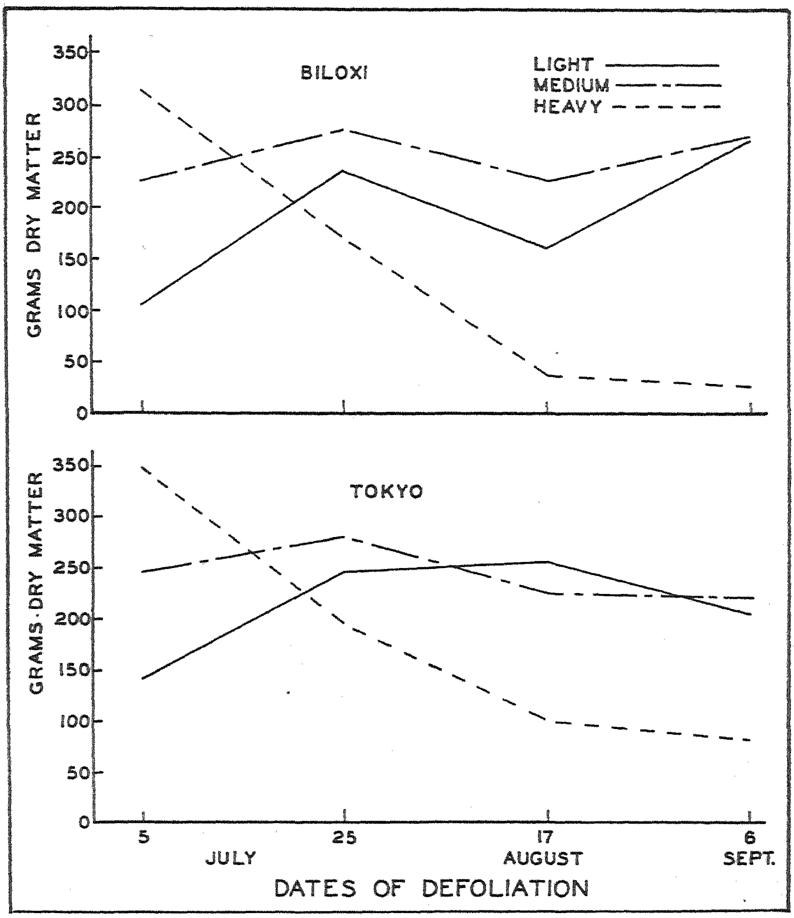

FIG. 2.—Dry weight of soybean leaves when defoliated at 20-day frequency. *Light*, removal of all but six leaves; *medium*, removal of all but three leaves; *heavy*, removal of all leaves throughout growing season.

With two exceptions, the means of each degree of defoliation increase as the time interval between defoliations increases. The 30-day medium-bud removed treatment mean of the Biloxi was slightly less than the corresponding 20-day mean. There was also a slight difference in the 10- and 20-day Tokyo means of lightly defoliated plants.

There is a highly significant interaction between the degree of frequency of defoliation. Except for severely defoliated Tokyo plants, the differences between comparable 10- and 20-day means are slight, being less than the differences between the 20- and 30-day means. The Biloxi shows little increase in productivity when lightly or severely defoliated every 20 days as compared with the 10-day treatment. A marked difference in the weight of stems and roots, however, results from the lengthening of the interval between these treatments from 20 to 30 days.

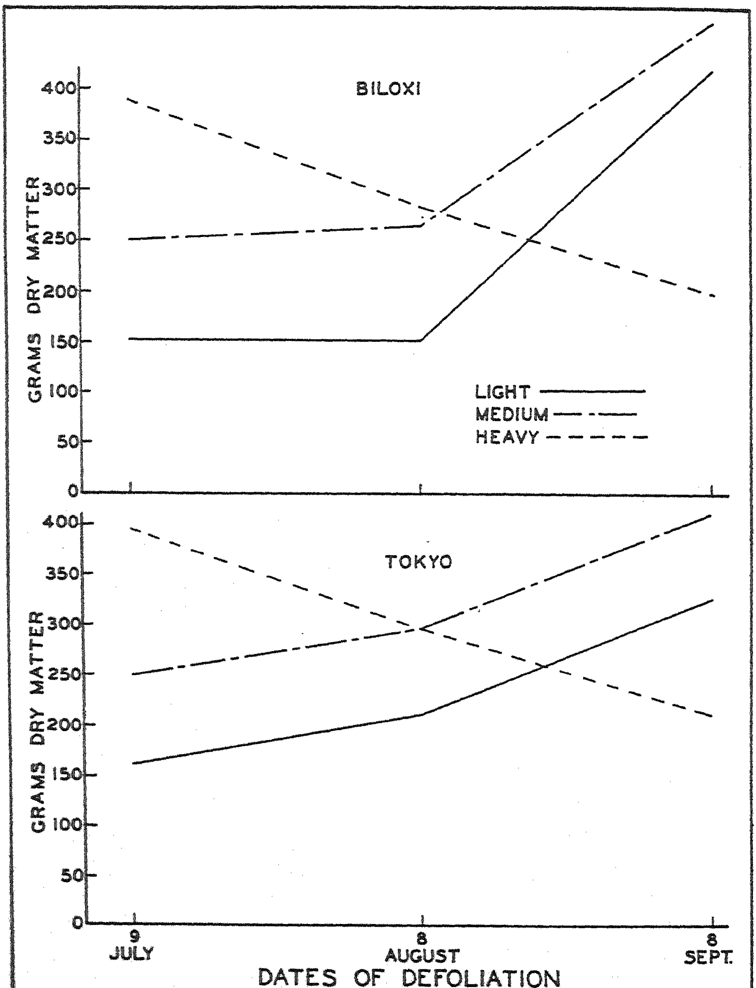

FIG. 3.—Dry weight of soybean leaves when defoliated at 30-day frequency. *Light*, removal of all but six leaves; *medium*, removal of all but three leaves; *heavy*, removal of all leaves throughout growing season.

WEIGHTS OF BEANS

The weights of beans produced by plants receiving each defoliation treatment are indicated in Table 4. Since data on the severe defoliation treatments were not included in the statistical analysis, the frequency means do not include these data. The Tokyo is superior to the Biloxi as a bean producer. The effect of the frequency of defoliation was similar for the two varieties. The mean of the check is significantly larger than the mean of any other treatment. Differences between the 10- and 20-day means might have been due to random variation, but both were significantly lower than the 30-day mean.

TABLE 4.—*Dry weight of beans in grams.*

Degree of defoliation	Biloxi				Tokyo			
	Frequency in days			Degree mean	Frequency in days			Degree mean
	10	20	30		10	20	30	
Severe	0	0	2	1	0	30	70	33
Medium bud removed	141	198	218	186	198	248	298	248
Medium	182	202	264	216	219	276	328	274
Light	266	205	292	254	377	378	455	403
Frequency mean	196	202	258	Check, 380	265	301	360	Check, 625

The least significant difference:
Between frequency means .47
Between degree means .47
Between degrees within any frequency .81

The yields of each variety were highest when plants were lightly defoliated and decreased as the treatments increased in severity. The removal of the terminal bud did not cause a significant reduction in the weight of beans produced. Though the light defoliation mean of the Biloxi is numerically larger than the medium treatment mean, the difference is not greater than that which might be attributed to random variation. The Tokyo means for these treatments are significantly different.

The analysis of the data shows that the major portion of the variation between treatments is due to the differences between the means of the check and the other treatments. Though the variation between degrees and between frequencies is highly significant, the interaction of degree and frequency is not significant. This means that the response of the plants to various frequencies of defoliation was similar as the degree of defoliation varied.

DISCUSSION

These experiments were conducted only one year and at one location, and the data must be interpreted in view of these limited observations. The results indicate that complete defoliation at any frequency was too severe a treatment for satisfactory growth and

productivity. The medium treatments were more efficient and resulted in significantly higher leaf production than the light or severe defoliations. Unlike many of the perennial grasses, the soybean is stimulated to maximum leaf productivity by the removal of some of the foliage during the period of vegetative growth. This conclusion is supported by the fact that low leaf yields were obtained following light defoliation at intervals of 30 days.

There is a highly significant interaction between the degree and frequency of defoliation. Light defoliation permitted most leaf growth when plants were defoliated every 10 days, while severely defoliated plants produced maximum growth with the 30-day recovery period. The fact that a longer interval between defoliations will partially reduce the ill effects of severe defoliation is of considerable practical importance.

In order that a supplementary pasture may be most useful, it must furnish pasturage when it is most needed. Under actual grazing conditions it is not possible to regulate the degree of defoliation with precision, but the recovery interval can be carefully controlled. The results of these experiments indicate that the soybean plant is physiologically capable of remaining productive in spite of wide variations in defoliation treatment. If these results are applicable to grazing conditions, the intensity of grazing may be varied according to particular needs without serious reductions in the total yield. If the need for forage is great, plants could be rather severely defoliated, provided a longer interval is allowed for recovery. If grazing requirements are not very great at any one time, but extend over a longer period, lighter grazing at more frequent intervals would probably be more efficient.

The seasonal productivity of leaves was affected by both the degree and frequency of defoliation. Yields from severely defoliated plants tended to decrease throughout the season, while yields increased as the season progressed when plants were lightly defoliated. The productivity of moderately defoliated plants was near the same level when 10 or 20 days were permitted for recovery, but increased with a 30-day interval.

Rainfall, temperature, and other ecological factors may be expected to affect the seasonal distribution of leaf yield. These influences are beyond the scope of the present paper. It might be noted, however, that the rainfall for June and July was below normal, while that for August was above normal. The periodicity and quantity of rainfall are listed in Table 5 for the period in which defoliations were made. Mean monthly temperatures were virtually normal for the entire growing season.

Differential responses of varieties of cutting treatments have been found in other species, and it seems reasonable to expect similar results with soybean varieties having different growth habits. The two varieties studied gave the same general types of response to the treatments, but differences in degree of response caused a significant variety-treatment interaction. Tokyo leaf yields were less affected by varying degrees and frequencies of defoliation than those of the Biloxi. Tokyo was also somewhat better adapted to the more frequent de-

foliations. Although the leaf yields from the highest Biloxi treatments were somewhat larger than those from Tokyo, there was no significant difference between the two varieties when all treatments were considered. If Tokyo should produce as well under actual grazing conditions as was indicated by these experimental yields, this variety should probably be seeded more frequently for supplementary pasture. Tokyo stems are somewhat weaker than those of Biloxi, and it is possible that they may be more subject to injury by grazing animals. This may account for the present wider popularity of the Biloxi variety.

TABLE 5.—*Periodicity and quantity of rainfall for periods of defoliation.*

July		August	
Date	Rainfall in inches	Date	Rainfall in inches
3	0.41	5	0.07
4	0.15	6	0.03
12	0.69	7	0.50
13	0.52	8	0.01
19	0.16	10	0.49
23	0.16	11	0.38
29	0.42	13	0.03
		14	4.36
		15	0.20
		16	0.08
		17	0.44
		24	0.32
		25	0.02
		27	0.12
		29	0.06
Total for month.....	2.51		7.11

For purposes of comparison the total dry weights of leaves (Table 1) have been converted to pounds per acre. The average yield of all treatments for each variety was approximately 1 ton dry weight of leaves per acre. The highest yields, 2,614 and 2,335 per pounds acre, were obtained by medium defoliation of Biloxi and Tokyo plants, respectively, at 20-day intervals. The leaf yields from lightly defoliated plants with a 30-day recovery period were 1,927 and 1,670 pounds per acre for Biloxi and Tokyo, respectively.

Complete defoliation at any frequency studied was too severe to permit effective seed production. The data indicate that the response of the plants to variations in the interval between defoliations was similar for all degrees of defoliation studied. The highest bean yields obtained from treated plants were only 75% of the yield from the undefoliated check. Corresponding treatments caused greater reduction of Tokyo than of Biloxi yields, but the Tokyo produced more beans in all treatments. The bean yields from the treatments resulting in the highest leaf yields were 50 to 70% of the check for Biloxi and 40 to 60% for Tokyo.

SUMMARY

The reaction of Biloxi and Tokyo soybeans to light, medium, and severe defoliation treatments at 10-, 20-, and 30-day intervals was studied during the 1940 growing season on a Congaree sandy loam soil. The results of this single trial may be briefly summarized as follows:

1. There was a highly significant interaction between the degree and frequency of defoliation.
2. Complete defoliation at any frequency was too severe for satisfactory growth.
3. Medium defoliation treatments resulted in significantly higher leaf yields than the light or severe treatments.
4. The leaf yields of the two varieties did not differ significantly. Tokyo leaf yields were less affected by varying degrees and frequencies of defoliation than those of Biloxi.
5. Weights of stems and roots were inversely related to severity of defoliation treatments.
6. Any degree of defoliation resulted in a decrease in the weight of seed produced. Yields tended to be inversely related to the severity of the defoliation.
7. Defoliation treatments caused greater reductions in seed yields of Tokyo than of Biloxi, but Tokyo produced more beans under all treatments.

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BORAX AND BORIC ACID FOR CONTROL OF FLIES IN MANURE[1]

A. R. Midgley, W. O. Mueller, and D. E. Dunklee[2]

FARMYARD manure and other rapidly decaying organic matter are the main breeding grounds for houseflies. Houseflies not only annoy both humans and animals but are also carriers of many diseases and parasites, such as typhoid, tuberculosis, dysentery, and intestinal worms (1),[3] as well as of infantile paralysis (7). The polio virus occurs at times in the contents of sewers and open privies, and flies feeding thereon have been found to contain it. Whether polio is usually or seldom thus spread, the possibility constitutes an additional reason for fighting the filthy fly.

The legs of the housefly are thickly covered with hairs and bristles which readily pick up germs whenever they come in contact with infected material. Then, subsequently, when human foods are contacted, they become contaminated with the germs. Many germs live for a long time in the fly's alimentary canal and are either voided in its excrement or extruded in small droplets of regurgitated matter from the mouth.

Farmyard manure and decaying organic matter not only serve as a source of food for flies and their larvae but provide a favorable environment for the development of the eggs. Fly eggs hatch quickly and larvae grow rapidly in horse manure because of its loose nature and its ready decomposition which engenders much heat. Cow manure, relatively wet and compact, is a less favorable medium, but with bedding, and under some conditions without it, the dryer portions promote fly multiplication.

The female fly usually deposits her eggs in the interstices below the surface of the mass of manure. Each female may lay 100 to 150 eggs at a time. These usually hatch the next day, the larvae emerging and feeding upon the decaying organic matter for 5 to 14 days. The larvae then pupate and the young flies emerge 3 to 10 days later. A new generation may arise within the space of 10 days to 2 weeks. The sudden appearance of clouds of flies near actively fermenting manure piles is due to this rapid multiplication and short life cycle.

While fly numbers can be reduced by the use of traps, sprays, and electric screens, a more complete control is needed. To that end their feeding and breeding places should be destroyed or rendered incapable of supporting larval growth. Farm manure, one of the main breeding and feeding mediums, obviously should not be destroyed or rendered unfit for crop fertilization, but should, if possible, be made unfit for the larval growth. An ideal larvaecide should be cheap, readily available, and, if possible, should increase the fertilizing value of the manure. Borax and boric acid seem to meet these requirements.

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[1]Contribution from the Agronomy Department, Vermont Agricultural Experiment Station, Burlington, Vt. Received for publication April 2, 1943.

[2]Research Agronomist, former Assistant Research Agronomist, and Assistant Research Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 785.

VARIATION IN FLIES AND MANURE

Preliminary trials showed that it was difficult to obtain equal infestation of eggs in similar samples of manure naturally exposed to flies. The physical condition of the exposed surface of the manure greatly influenced the choice made by the fly in laying its eggs, especially in small experimental samples. In most trials attempts were made to simulate actual barn conditions by using large amounts of manure as nearly uniform in character as possible. In most cases a known number of eggs were planted in the manure, thus insuring uniformity and comparability in this respect. The hatch of flies depends to a large extent on the weather. Under Vermont conditions good hatches were certain only in midsummer.

To overcome variation in flies as much as possible, a dependable source of flies is necessary. Eggs were obtained from fresh horse manure, a small pile of which, exposed to flies, was found to supply all that were necessary. Egg clusters thus obtained were carefully placed among the surface cracks of the manure, but not mixed into the mass under test. While strips of meat and other moist protein substances readily attract flies and offer a good means for obtaining eggs, these types of bait often attract green blow flies, a quite different genus not desirable for this study.

BORAX FOR CONTROL OF FLIES IN CATTLE MANURE

Granular borax was mixed with fresh portions of cow manure in amounts equal to 1, 2, 4, 5, and 6 pounds per ton of manure. These five mixtures, together with an untreated check, were placed in 2-gallon stoneware jars and each inoculated with about 400 fly eggs. A fly trap was then placed securely on the top of each jar until such time as the flies ceased to hatch. The numbers of mature flies caught in the traps are shown in Table 1.

TABLE 1.—*Effect of increasing rates of borax on the control of flies in cattle manure, approximately 400 eggs added to each jar.*

Borax per ton of manure, lbs.	Number of flies hatched
None	400
1	405
2	385
4	100
5	80
6	10

These data show that unless at least 4 pounds of borax per ton of manure were used multiplication of flies was not reduced. When 6 pounds were used, the number of flies was drastically cut. This amount, on a volume basis, is similar to that suggested by Bishopp (1) and Cook, *et al.* (2) in which they used 0.62 pound of borax per 8 bushels of *horse* manure. They dissolved the borax in about 10 gallons of water and sprinkled this upon the manure. For such manure it may be necessary to dissolve the borax first since there is insufficient liquid for adequate penetration of borax in relatively

dry horse manure. Since borax dissolves very slowly in cold water, it would be quite difficult, if not impossible, to apply it thus in the average dairy barn.

Since borax acts as a poison to the fly larvae, it should be well distributed at points where they feed. The adult flies which emerged from the treated manure in the writers' trials apparently were able to avoid areas containing the highest concentration of borax.

Several preliminary trials indicate that borax is more effective if sprinkled in the bottom of the cleaned gutter. Thus placed, the urine is better able to dissolve the borax and it becomes well mixed with the manure when removed from the stable. Further work needs to be done along this line.

BORIC ACID FOR CONTROL OF FLIES IN CATTLE MANURE

Theoretically, boric acid should be more effective than borax as a manurial amendment. It is a weak acid and, to some extent, inhibits nitrogen escape into the air; in fact it is sometimes used for this purpose in Kjeldahl nitrogen determinations (3). Borax, on the other hand, is alkaline and tends to drive some ammonia from manure. Boric acid is more readily soluble than borax and contains half again as much boron. Hence, an equivalent amount of boron can be more readily dissolved in the form of boric acid.

MIXED WITH MANURE

One hundred-pound quantities of fresh cow manure were each thoroughly mixed with boric acid at rates of 2½ and 5 pounds per ton of manure. A similar amount of manure was left untreated for comparison. All lots were exposed to flies for 6 days for natural egg inoculation and then covered with fly traps. The trial was carried on simultaneously in two dairy barns. The number of mature flies hatched and trapped are shown in Table 2.

TABLE 2.—*Effect of mixing boric acid with manure on the multiplication of flies.**

Boric acid per ton of manure, lbs.	Number of flies hatched	
	Barn No. 1	Barn No. 2
None	5,800	658
2.5	500	110
5	20	16

*Exposed 6 days to flies; no eggs added.

The use of boric acid at the rate of 2.5 pounds per ton of manure materially reduced fly numbers, while very few survived when 5 pounds were applied. Many more flies were seen near barn No. 1 than around barn No. 2 which, no doubt, accounts for the larger number hatched in the former case. These data give striking evidence of the rate at which flies may multiply in small amounts of untreated manure, nearly 6,000 emerging from 100 pounds.

BORIC ACID IN GUTTER

Boric acid to be most effective should be completely dissolved and well distributed in the manure. This might be accomplished by applying it in the bottom of the barn gutter where the urine may come into contact with it, especially in water tight gutters. It might be possible thus to effect a better control of flies than by mixing boric acid with the manure. Therefore, boric acid in amounts equivalent to 2.5 and 5 pounds per ton of manure was used under actual barn conditions in the cleaned gutter. One hundred pound portions of manure produced in the treated and untreated gutters were placed in large cans (ash barrels), inoculated with about 1,500 eggs, and then covered with fly traps. A similar trial was conducted at a later date in which smaller quantities of manure were employed with only about 500 fly eggs (Fig. 1). The results from these two trials are presented in Table 3.

TABLE 3.—*Effect of boric acid in the gutter on the control of flies.*

Boric acid per ton of manure, lbs.	Number of flies hatched from	
	About 1500 eggs 1st trial	About 500 eggs 2nd trial
None	1,559	518
2.5	20	28
5.0	3	0

These data definitely show that 2.5 pounds of boric acid per ton of manure is very effective in reducing the fly population. Sprinkling

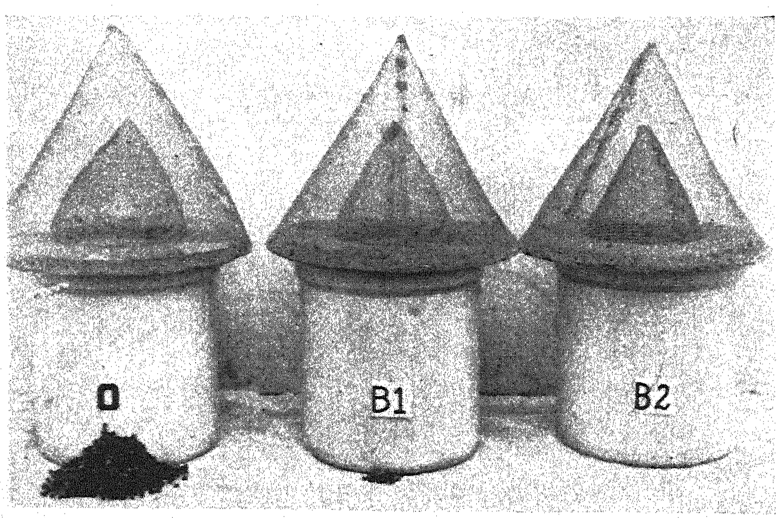

FIG. 1.—Effect of mixing boric acid with manure on the multiplication of flies. O, no boron; B1, boric acid 2.5 pounds per ton of manure; B2, boric acid 5 pounds per ton of manure.

of boric acid in the gutter appears more effective than subsequent mixing with the manure (Table 2), although the trials were so conducted that the results are not directly comparable.

BORIC ACID APPLIED TO OUTSIDE OF A MANURE PILE

Manure piles are ideal breeding places for flies. Since the larvae feed near the surface, it should be possible to poison them by applying boric acid to the outside of the pile. Preliminary trials showed that tight wood or concrete floors were needed for experiments since the larvae may travel a considerable distance from the pile if it is in contact with the soil. This is particularly true just previous to the pupation period.

Dry boric acid equivalent to 5 pounds per ton of manure was spread over a 250-pound conical pile, a similar pile being left untreated. An attempt was made to dissolve the boric acid by sprinkling a little water over the entire pile, an equivalent amount of water being also applied over the untreated manure. The piles were left exposed to natural infestation for 4 days and then covered with large screen cages containing suitable fly traps. The data relative to flies caught are presented in Table 4.

TABLE 4.—*Effect on control of flies of applying boric acid to the outside of the manure pile.*

Boric acid per ton of manure	Number of flies hatched
None	3,530
5 pounds on top of pile; watered-in	515

The results show that the application of boric acid to the outside of a manure pile, followed with some water, markedly reduced the fly population but was less effective than the other methods tried. Only one trial was made. The boric acid may not have been thoroughly dissolved and carried down into the manure. Better control might result if it was dissolved before use.

When applied to the outside of the pile, much of the boric acid is concentrated in the surface area. However, it must be present in the moist feeding range of the larvae in order to poison them. In actual practice this may be accomplished during a heavy rain, but since flies may complete their life cycle within a week or two, one should not depend upon rain for dissolving and carrying the boric acid into the pile. If a manure pile is to be treated, the writers suggest that the boric acid be dissolved in water (preferably warm) before applying. The larvae feed near the surface where they can obtain air; thus, it is not necessary to poison or treat the central portion of the pile.

DISCUSSION

Cow manure containing ordinary amounts of bedding offers a very good breeding medium for flies. Thus, in one instance, nearly 6,000 flies hatched from 100 pounds of manure which had been exposed in the barn for 6 days. Many generations of flies may be produced in one

season since a new one may start every 2 weeks. Temperature, humidity, and character and abundance of food control the number of flies produced. Since flies may feed and breed in human excrement, they are potential carriers of many diseases including polio, the virus of which may occur in human bowel discharges.

Flies are best controlled by destroying their breeding places or rendering them incapable of supporting larval growth. Manure hauled daily in the summer and spread thinly dries quickly. This is fortunate since it checks the multiplication of flies. However, summer is a busy time on the farm. Furthermore, many eggs are laid in the manure while it lies in the gutter and these may hatch within 24 hours. If the larvae attain a fairly good size before the manure completely dries in the field, they can continue to develop and to pupate in the soil. Because of these circumstances, poisoning of the larvae in the manure is necessary for effective checking of reproduction. Borax or boric acid serve well for this purpose since their use reduces fly numbers and at the same time provide boron for crop growth. Previous studies have shown that under Vermont conditions, boron contributes to the maintenance of successful alfalfa stands (4, 6).

Boric acid seems to control flies better than borax, being more soluble and containing more boron per unit weight. Moreover, it results in some saving of nitrogen whereas alkaline borax tends to drive off nitrogen. Both seemed most effective when sprinkled in the stable gutter, being thus dissolved by the urine and becoming well mixed with the manure. An easy way to apply the small amount needed is to use a quart can with suitable holes in the bottom for spreading. A quart of borax weighs about 2 pounds. If piled manure is treated, the material should be dissolved in water and then the water sprinkled over the exterior.

There are definite limits to the amount of either borax or boric acid that can be safely tolerated in manure used as a fertilizer. An overdose will harm crops, but 2.5 to 3 pounds of boric acid or an equivalent amount of borax per ton of manure should not be injurious to alfalfa if not more than 10 tons of manure per acre are used in the field. Twice as much borax has been used on alfalfa with helpful rather than harmful results. Other crops may be less tolerant. Since only summer-produced manure need be treated for fly control and since there is little voided in the stable during that season of the year, this small amount of borated manure could well be used on alfalfa, orchards, or soils recently limed. Liming tends to increase the need of crops for boron and also reduces toxicity if too much boron is used (5). By exercising care to see that 30 to 40 pounds of boric acid per acre or its borax equivalent is not exceeded in the field, these materials applied in the barn gutter can be made to serve the dual purpose of summer fly control and of providing fertilizer boron for alfalfa.

SUMMARY

Borax and boric acid were tested for the control of flies in cattle manure.

It was found necessary to plant a known number of fly eggs in the surface cracks of the manure samples under test to insure experi-

mental uniformity in eggs. A pile of exposed fresh horse manure provided an ample supply of eggs.

Boric acid was more effective than granular borax on the same boron basis. This is probably because the acid is more soluble.

Best results were obtained when 2½ to 3 pounds of boric acid per ton of manure were placed in the bottom of the cleaned barn gutter. In this position the material dissolves in the urine and thus insures better subsequent mixing with the manure. This amount of boric acid gave good fly control and at the same time the treated manure is a good source of boron for alfalfa and orchards when used at rates not exceeding 10 tons per acre. Only summer-produced manure need be treated in this way.

Piled manure left during the summer is an ideal breeding ground for flies. If this manure cannot be spread, the surface should be sprayed or sprinkled with borax or boric acid in solution at the above rates.

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GERMINATION OF 20-YEAR-OLD WHEAT, OATS, BARLEY, CORN, RYE, SORGHUM, AND SOYBEANS[1]

D. W. ROBERTSON, A. M. LUTE, AND H. KROEGER[2]

THE knowledge that farm seeds when stored in a dry atmosphere maintain their viability over a long period of years may be of value in the storage of reserve seed stocks to meet war and post-war needs. The data reported in this paper are from a study of seeds stored for periods varying from 1 to 22 years.

The literature on storage of farm seeds was reviewed in previous papers by the authors and will not be discussed here.[3] Previous results[4] have shown that seeds of wheat, oats, and barley stored under arid climatic conditions declined slowly for the first 10-year period with a sharp break in germination between the tenth and twelfth years. There were indications of different reactions to storage between six-rowed hulled, two-rowed hulled, and six-rowed hulless barley.

Rosen rye and Wisconsin Black soybeans did not maintain their viability to the same degree as wheat, oats, and barley.

Black Amber sorghum still maintained an excellent germination percentage after being stored for 10 years, and Yellow Dent corn germinated well for the first 6 years and dropped off rapidly between the ninth and tenth years. The results reported in this paper are a continuation of the previous work reported by the authors.

EXPERIMENTAL METHODS

The first tests were made in 1921 on the 1920 crop. The grains were threshed, cleaned, and stored in 100-pound sacks, which were then placed in an unheated room. They were stored in the same room during the entire period of the test. Samples were taken in February of each succeeding year. Composite samples from each sack were made by mixing grain drawn from the sacks by a grain probe and by taking off a portion with a small scoop. Germination tests were made before July 1 of each year. Crops from the succeeding years, 1920–29, were saved when grown and placed in the storage room. Only perfect seeds were used for germination, broken and damaged seeds being discarded. In the later years of the experiment, considerable damage was done by the dermestid beetle (*Trogoderma tarsale*). All damaged seeds were discarded. The storage room was sprayed with an ethylene dichloride-carbon tetrachloride mixture to control insect pests.[5] The crops used were the standard varieties of cereals shown in Table 1.

[1]Contribution from the Section of Agronomy, Colorado Agricultural Experiment Station, Fort Collins, Colo. Authorized by the Director of the Colorado Agricultural Experiment Station for publication as Scientific Journal Series Article No. 162. Received for publication April 3, 1943.

[2]Agronomist, formerly Seed Analyst, and Seed Analyst, respectively.

[3]ROBERTSON, D. W., and LUTE, ANNA M. Germination of the seed of farm crops in Colorado after storage for varying periods of years. Jour. Agr. Res., 45:455–462. 1932.

[4]ROBERTSON, D. W., and LUTE, ANNA M. Germination of seed of farm crops in Colorado after storage for various period of years. Jour. Amer. Soc. Agron., 29:822–834. 1937.

[5]The mixture used was ethylene dichloride 3 parts and carbon tetrachloride 1 part by volume, according to Roark, R. C., and Cotton, R. T. Tests of various alipathic compounds as fumigants. U. S. D. A. Tech. Bul. 162. 1929.

TABLE 1.—*Varieties of seed studied and years in which they were grown.**

Crop	Variety	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
Spring wheat...	Marquis		+	+	+	+	+	+	+		+
Winter wheat...	Kanred		+			+					+
Spring wheat...	Defiance			+		+		+	+		
Durum wheat...	Kubanka		+	+							+
Oats......	Colorado 37	+		+	+	+	+	+	+	+	+
	Great Dakota			+	+						
	Swedish Victory	+		+							
	White Russian	+									
	Gold Rain						+	+			
	Nebraska 21			+		+	+	+	+	+	+
Barley.....	Nepal	+	+	+	+	+	+				
	Success	+	+	+							
	Colsess			+	+	+	+	+	+	+	+
	Coast	+	+		+	+	+				
	Hanna	+		+							
	Gold	+									
	Moister						+	+	+		
Winter rye.	Rosen			+	+	+				+	
Soybean...	Wisconsin Black				+	+					
Sorghum ..	Black Amber						+	+	+		
Corn......	Yellow dent		+	+	+	+					

*Plus mark signifies crop was grown in year indicated.

From an examination of the humidity records, there appears to be no connection between the average annual relative humidity and the original germination percentage. Humidities for all years were low. The actual percentage of moisture in the seed samples was determined for the 1929 crop and was found to range between 9.5 and 11.4. No tests were made on the other crops. In later studies, Robertson, Lute and Gardner[6] found there was a close relationship between the relative humidity and moisture content of the grain. The 1929 figures would, therefore, indicate that the relative humidity in the storage room was very low.

RESULTS

The germination tests made the year the seeds were harvested ranged from 93.0 to 98.5% for Marquis, 84.0 to 90.0% for Kubanka, and 93.0 to 95.0% for Kanred wheat (Table 2). Barley and rye showed a greater variation than wheat and oats from year to year and for different varieties. The germination percentage of oats did not differ greatly from that of wheat.

The general trend seems to indicate that oats, barley (covered), and Marquis and Kanred wheat have a high percentage of germination the first year, while Kubanka wheat, Nepal barley (naked), and Rosen rye show a lower germination percentage the first year.

[6]ROBERTSON, D. W., LUTE, A. M., and GARDNER, ROBERT. Effect of relative humidity on viability, moisture content, and respiration of wheat, oats, and barley seed in storage. Jour. Amer. Soc. Agron., 59:281–292. 1939.

The germination percentages of wheat, oats, and barley are presented in Table 3 and are shown graphically in Fig. 1. The general trend of all the crops is similar. Germination holds up for the first 10 years, dropping only about 5% lower than the original germination. In the next 5 years the drop is greater, as is indicated by the increased slope of the curve in Fig. 1. Wheat dropped more in germination percentage than did either oats or barley. From the fifteenth to the twenty-first years wheat dropped from 72% to 12%, while oats and barley dropped from about 80% to between 40 and 50%. These data indicate that wheat, oats, and barley hold up their germination for a 10-year period when stored under climatic conditions prevailing at Fort Collins, Colo. When 15 years old they may be considered to have sufficient viability to justify their planting in the field. In the next six years (fifteenth to twenty-first years), wheat loses its germination rather rapidly, but barley and oats still germinate about 50%. The small number of crops after the thirteenth year reduce the value of the data somewhat, but at the end of the period we still have three wheat crops, three oat crops, and five barley crops. At 13 years, each dot on the curve (Fig. 1) represents the following number of crops tested: For wheat, 18; for oats, 23; and for barley, 32.

The data in Table 3 show the germination percentages calculated as a percentage of the first year's germination. This accounts for the apparent increase in germination percentage in some of the varieties. The standard error was calculated from the actual percentage germination for the first year and from the calculated percentages for the other years. The results for the corn crop give actual germination throughout. The same is true of White Russian oats. Unfortunately, germination tests were not obtained the first year on some of the corn and on White Russian oats, so calculations could not be made on the basis of 1-year-old seed.

DISCUSSION

WHEAT VARIETIES

The comparative percentage germination of the various crops is given in Table 3. As previously mentioned, the number of crops tested drops off as the crops increase in age. This is due to the fact that they were produced in different years over a 10-year period. The fact that fewer crops are available as they advance in age may have some influence on the value of the data from the older crops. However, the trend seems to be consistent for all crops tested. Three varieties of *Triticum vulgare* and one variety of *T. durum* are represented in the table. When we consider the average germination of all wheat varieties tested, it will be noted that the germination drops slightly each year until the twelfth year and then takes a marked drop. This is also shown in Fig. 1.

When we consider the drop in germination percentage by 5-year periods, it will be noted that there is a decline of 2.8 for the first 5-year period, 5.3 for the second 5-year period, 27.6 for the third 5-year period, and 76.0 for the fourth 5-year period.

The different varieties when analyzed separately show a similar trend and do not present any marked varietal difference for the first 20 years.

BARLEY VARIETIES

The results of the tests of barley varieties are shown in Table 3. The average germination of all barleys in percentage shows a gradual decline for the first 12-year period with a slight drop for the next 3 years and a sharp drop for the next 7 years. This is shown graphically in Fig. 1. When the germination data are examined, it will be seen that a drop of 6.6% was obtained for the first 10 years and 14.3% in the next 5 years, with a drop of 49.1% in the 5-years between 15 and 20 years. In Table 3 the various types of barley are grouped. It will be noted that the six-row covered hooded barleys and the six-rowed covered awned barleys are somewhat higher in germination throughout than the average for all barleys.

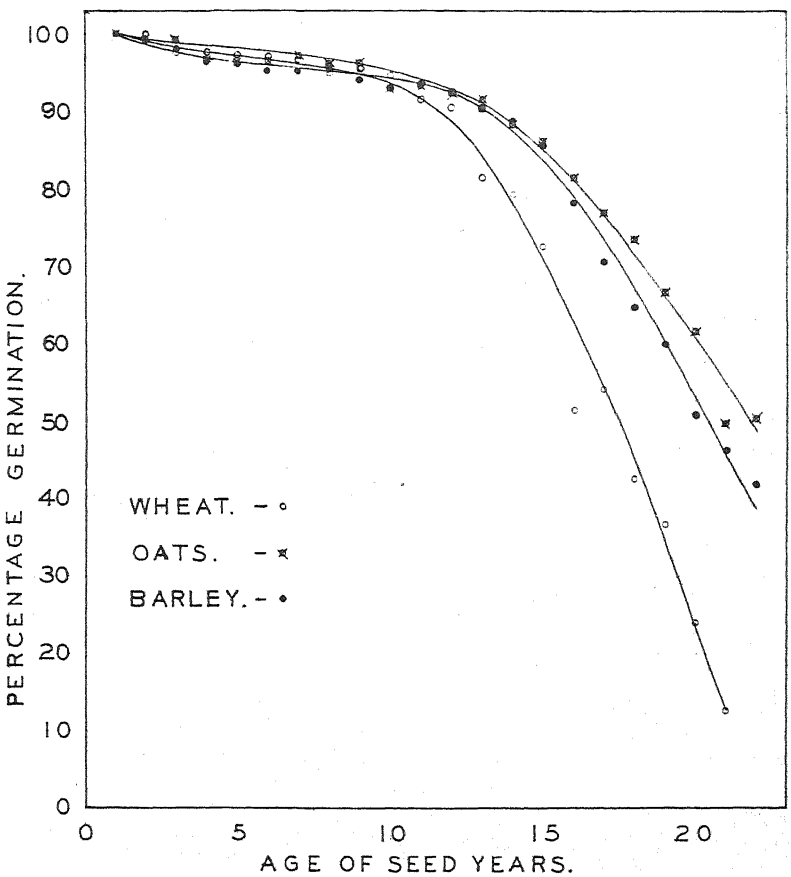

FIG. 1.—Curves showing the relationship between age of seed in years and percentage germination of wheat, oats, and barley.

TABLE 2.—*Germination percentages for various crops harvested in different years.*

Variety	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
					Wheat					
Marquis	—	98.0	97.5	93.0	93.5	97.5	95.5	98.5	—	97.0
Defiance	—	—	96.0	—	89.0	—	90.5	98.5	—	—
Kanred	—	95.0	—	—	94.0	—	—	—	—	93.0
Kubanka	—	88.0	90.0	—	—	—	—	—	—	84.0
					Barley					
Nepal	87.0	95.5	95.0	73.0	69.0	84.0	—	—	—	—
Success	98.5	99.5	96.0	—	—	—	—	—	—	—
Colsess	—	—	99.5	98.5	97.0	97.0	94.0	97.0	97.0	99.5
Coast	97.0	94.0	—	98.5	92.0	96.5	—	—	—	—
Trebi	—	—	—	—	—	—	97.0	—	—	91.5
Hanna	90.5	—	96.0	—	—	—	—	—	—	—
Gold	95.5	—	—	—	—	—	—	—	—	—
Moister	—	—	—	—	—	98.5	96.0	97.0	—	—
Elfry	—	—	—	—	—	99.5	—	—	—	—
Smyrna	—	—	—	—	—	—	—	91.5	—	—
					Oats					
Colorado 37	98.0	—	99.0	99.0	98.0	97.0	97.0	95.0	98.5	98.0
Nebraska 21	—	—	97.0	—	97.5	95.5	94.0	98.0	—	92.0
Swedish Victory	99.0	—	99.5	—	—	—	—	—	—	—
Gold Rain	—	—	—	—	—	95.5	97.0	—	—	—
Great Dakota	—	—	99.5	99.0	—	—	—	—	—	—
					Miscellaneous Crops					
Rosen rye	—	—	98.0	83.5	84.0	—	—	—	—	83.5
Wisc. Black soybeans	—	—	—	93.5	—	—	—	—	—	—
Black Amber sorghums	—	—	—	—	—	—	—	62.0	—	—
Minn. 13 corn	—	—	—	85.0	98.0	—	—	—	—	—

The naked barleys are lower throughout. The two-rowed barleys hold up for the first 5-year period but drop noticeably in the last 15-year period. From these data it may be concluded that the varieties tested show some varietal differences in their ability to maintain viability over a period of 20 years. Nepal C.I. 595 and the two-rowed barleys, Gold and White Smyrna, drop off much quicker in germination after the first 5-year period of storage.

OAT VARIETIES

Both midseason and early oats are included in the test. Unfortunately, when the study was started red oats, *A. byzentina*, were not being grown extensively in Colorado, and therefore, were not included in the studies. As will be seen from Table 3 and Fig. 1, oats followed very closely the same type of decrease as did barley. A drop of 2.5% was noted in the first 5-year period, 5.9% in the second period, 14.0% in the third period, and 38.4% in the fourth period. The germination percentage in the twentieth year is the average of seven samples.

OTHER CROPS

The data obtained on the other crops are less complete, and the number of crop years per crop is less. The data from dent corn, rye, sorghum, and soybeans is given in Table 3 and graphically in Fig. 2. It will be noted from Fig. 2 that corn (actual germination) drops off rather uniformly for the 21-year period of the test. Unfortunately, the test is not as complete as some of the others, but at the end of 21

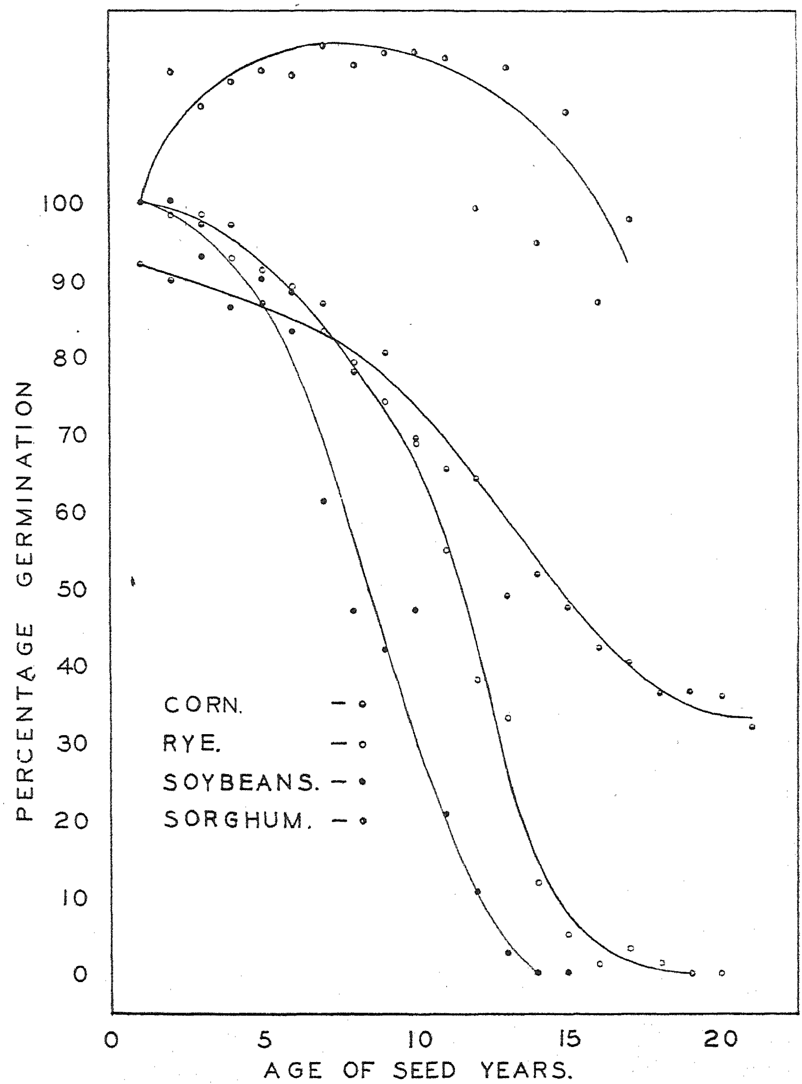

FIG. 2.—Curves showing the relationship begween age of seed in years and percentage gernimation for corn, rye, soybeans, and sorghums.

TABLE 3.—*Comparative percentage germination and number of crops tested in indicated number of years after harvest.*

Variety	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Wheat																						
Marquis C. I. 3641:																						
Germination, % . . .	100	99.8	98.2	96.0	97.0	96.5	95.4	94.6	95.7	94.8	92.0	90.2	80.8	78.8	63.4	56.5	49.4	46.6	35.1	26.1	11.2	—
No. crops tested	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	6	5	4	3	2	1	—
Defiance:																						
Germination, % . . .	100	98.4	99.3	98.2	97.3	97.0	98.7	96.5	97.4	94.7	89.6	91.8	88.9	81.8	68.2	57.1	71.0	38.7	20.8	9.4	—	—
No. crops tested	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	2	2	1	1	—	—
Kanred C. I. 5146:																						
Germination, % . . .	100	102.5	98.4	101.4	97.5	98.3	97.0	94.1	95.8	98.4	93.4	90.9	75.1	67.9	70.4	54.5	54.0	27.5	15.8	12.6	2.1	—
No. crops tested	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	1	1	1	—
Kubanka C. I. 1440:																						
Germination, % . . .	100	100.6	94.5	97.5	97.5	97.7	98.1	95.0	87.6	90.9	91.4	88.7	81.3	87.1	78.2	63.4	49.0	54.6	57.9	34.9	25.0	—
No. crops tested	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	1	
All varieties:																						
Germination, % . . .	100	100.1	97.9	97.7	97.2	97.1	96.8	95.0	95.7	94.7	91.6	90.4	81.7	79.2	72.4	51.4	54.1	42.8	36.8	24.0	12.8	—
No. crops tested	18	18	18	18	18	18	18	18	18	18	18	18	18	15	14	13	11	10	7	6	3	—
S. E. of mean	0.97	0.67	0.88	1.02	0.92	0.96	1.29	0.82	1.22	1.10	1.03	1.60	2.57	—	—	—	—	—	—	—	—	—
Barley																						
Nepal C. I. 595:																						
Germination, % . . .	100	99.3	89.8	86.2	88.3	85.9	90.4	93.4	89.1	86.5	93.7	88.5	87.8	82.7	77.3	65.0	54.5	46.8	38.2	32.7	24.5	13.8
No. crops tested	6	6	4	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	4	3	2	1
Success:																						
Germination, % . . .	100	97.8	95.3	97.0	98.5	94.1	96.4	94.9	89.8	91.5	89.6	89.6	90.3	89.2	90.8	86.5	78.5	74.2	72.2	64.3	60.2	53.8
No. crops tested	3	3	1	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1
Colsess C. I. 2792:																						
Germination, % . . .	100	98.5	98.0	98.5	97.6	97.9	97.2	97.5	97.0	97.6	96.7	95.3	94.5	93.0	90.8	82.6	80.4	80.6	72.2	70.4	—	—
No. crops tested	8	8	8	8	8	8	8	8	8	8	8	8	8	7	6	5	4	3	2	1	—	—
Coast:																						
Germination, % . . .	100	100.5	100.1	99.6	98.6	98.8	98.3	98.4	98.2	97.9	97.1	97.1	97.0	97.2	92.9	88.9	87.3	84.8	79.7	69.8	66.6	71.1
No. crops tested	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	3	2	2	1
Trebi C. I. 936:																						
Germination, % . . .	100	96.1	100.7	97.0	100.9	99.8	99.1	97.2	99.0	99.8	94.5	98.2	95.1	79.4	86.6	82.5	—	—	—	—	—	—
No. crops tested	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	—	—	—	—	—	—

Ianna:																						
Germination, %...	100	97.2	104.2	99.0	100.4	94.9	90.2	90.8	90.7	86.6	87.1	84.1	80.8	76.5	73.3	62.9	52.4	45.9	54.4	38.4	33.1	32.0
No. crops tested....	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
;old C. I. 1145:																						
Germination, %...	100	97.4	99.5	98.4	93.7	87.4	81.0	79.1	78.0	68.1	74.9	84.3	66.5	69.1	66.0	57.6	51.3	37.7	38.7	33.5	33.5	38.7
No. crops tested....	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Aoister C. I. 2799:																						
Germination, %...	100	99.8	99.3	99.6	95.6	97.6	96.1	96.3	96.4	91.6	94.0	93.7	88.9	93.1	91.3	87.0	81.2	—	—	—	—	—
No. crops tested....	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1	—	—	—	—	—
Ilfry C. I. 2800:																						
Germination, %...	100	100	99.0	96.5	89.4	95.0	94.5	93.0	92.5	91.5	88.4	86.4	81.4	85.4	77.4	86.4	79.4	—	—	—	—	—
No. crops tested....	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	—	—	—	—	—
Vhite Smyrna:																						
Germination, %...	100	106.6	102.7	106.0	104.9	104.9	102.7	103.8	102.7	100.5	95.6	102.7	92.9	97.3	88.5	—	—	—	—	—	—	—
No. crops tested....	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	—	—	—	—	—	—	—
ll barleys:																						
Germination, %...	100	99.1	98.1	96.4	96.1	95.1	95.2	95.6	94.1	93.4	93.6	92.7	90.5	88.8	85.7	78.2	70.7	64.8	60.0	50.9	46.2	41.9
No. crops tested....	32	31	28	31	31	32	32	32	32	32	32	32	32	30	29	26	22	18	15	12	8	5
S. E. of mean......	1.24	0.63	0.91	1.32	1.21	1.30	1.80	1.57	1.57	1.86	1.61	1.93	1.86	2.23	2.28	—	—	—	—	—	—	—
Iaked barleys:																						
Germination, %...	100	99.3	89.8	86.2	88.3	85.9	90.4	93.4	89.1	86.5	93.7	88.5	87.8	82.8	77.3	65.0	54.5	46.8	38.2	32.7	24.5	13.8
No. crops tested....	6	6	4	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	4	3	2	1
-rowed hulled hooded barley:																						
Germination, %...	100	98.3	97.7	98.2	97.8	96.9	96.9	96.9	95.0	95.9	94.7	93.8	93.3	91.8	90.8	84.0	79.6	77.4	72.2	65.8	60.2	53.8
No. crops tested....	11	11	9	10	10	11	11	11	11	11	11	11	11	10	9	8	7	6	5	4	2	1
-rowed hulled awned barley:																						
Germination, %...	100	99.5	100	98.9	97.5	98.3	97.5	97.1	97.3	96.0	95.0	95.4	93.0	93.0	90.2	87.5	85.3	84.8	79.7	69.8	66.6	71.1
No. crops tested....	11	11	9	10	10	11	11	11	11	11	11	11	11	10	10	9	7	4	3	2	2	1
-rowed hulled awned barley:																						
Germination, %...	100	98.4	102.6	100.6	99.8	95.5	91.0	91.1	90.5	80.4	83.0	84.1	76.0	74.0	70.8	61.1	52.0	43.2	49.1	36.7	33.3	35.4
No. crops tested....	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	2	2
Oats																						
olorado 37:																						
Germination, %...	100	100.1	99.4	98.0	97.6	97.2	98.6	95.9	97.1	95.2	94.7	92.7	91.8	89.1	85.6	81.7	80.5	72.8	64.8	71.0	59.2	60.2
No. crops tested....	9	8	9	9	9	9	9	9	9	9	9	9	9	8	7	6	5	4	3	2	1	1
lebraska 21:																						
Germination, %...	100	100.6	99.1	98.4	98.6	98.3	97.9	97.4	97.0	95.5	91.3	92.4	90.2	88.1	81.5	78.2	64.8	61.6	67.0	53.6		
No. crops tested....	6	6	7	7	6	7	7	7	7	6	7	7	6	5	5	4	3	2	1	1		

*Actual germination on two samples of Northwestern Dent and four samples of Yellow Dent.

TABLE 3.—*Concluded.*

Variety	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
										Oats—*Continued*												
Swedish Victory:																						
Germination, % . . .	100	95.0	99.3	97.8	93.5	92.7	94.5	92.7	91.0	88.7	93.2	88.4	92.5	87.4	90.7	81.6	80.1	77.6	75.6	69.0	65.7	65.7
No. crops tested	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
Gold Rain:																						
Germination, % . . .	100	99.5	99.9	97.1	98.5	96.6	97.1	99.5	98.4	100.3	94.0	97.2	95.6	95.1	94.0	93.5	78.5	—	—	—	—	—
No. crops tested	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	—	—	—	—	—
Great Dakota:																						
Germination, % . . .	100	97.8	97.8	95.7	96.5	94.8	93.0	95.5	91.9	86.7	93.5	90.2	88.2	85.2	84.2	77.6	82.6	75.1	80.1	74.4	—	—
No. crops tested	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	—	—
White Russian:																						
Germination, % . . .	—	98.5	—	97.0	98.0	95.0	93.5	94.5	97.5	88.0	95.0	89.5	95.5	78.5	88.0	77.0	76.0	54.0	28.0	23.0	24.0	25.0
No. crops tested	—	1	—	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
All varieties:																						
Germination, % . . .	100	99.6	99.2	97.8	97.5	96.8	97.2	96.3	96.2	94.1	93.4	92.2	91.6	88.4	86.0	81.5	76.9	73.5	66.7	61.6	49.6	50.3
No. crops tested	21	20	22	23	22	23	23	23	23	22	23	23	22	20	19	17	14	11	9	7	3	3
S. E. of mean	0.43	0.69	0.62	0.78	0.82	0.83	0.87	0.90	0.82	1.28	1.10	1.07	1.02	—	—	—	—	—	—	—	—	—
										Rye												
Rosen:																						
Germination, % . . .	100	98.3	98.4	92.9	91.4	89.4	83.5	79.2	74.2	68.9	55.0	38.1	33.1	11.9	5.1	1.2	3.2	1.6	0	0	—	—
No. crops tested	4	3	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	2	1	—	—
										Soybeans												
Wisconsin Black:																						
Germination, % . . .	100	101.1	93.0	86.6	90.1	83.3	61.2	47.0	42.0	47.1	20.7	10.7	2.7	0	0	—	—	—	—	—	—	—
No. crops tested	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	—	—	—	—	—	—	—
										Sorghum												
Black Amber:																						
Germination, % . . .	100	117.0	112.6	115.8	117.2	116.5	120.5	117.9	119.4	119.6	118.9	99.1	117.8	94.9	111.8	87.0	97.9	—	—	—	—	—
No. crops tested	1	2	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1	—	—	—	—	—
										Corn												
Corn*:																						
Germination, % . . .	92.0	90.0	97.0	97.0	87.0	88.4	86.9	78.0	80.4	69.6	65.5	64.1	49.0	51.7	47.5	42.2	40.3	36.3	36.6	36.0	32.0	—
No. crops tested . . .	2	1	2	2	2	5	6	6	5	6	5	6	6	6	6	6	6	6	5	3	1	—

*Actual germination on two samples of Northwestern Dent and four samples of Yellow Dent.

years the average germination was 32.0%. This indicates that stocks having a high initial germination when kept free from insect pests in a dry atmosphere could still be propagated after storage for 21 years.

Three samples of Black Amber cane harvested in different years were included in the test. All samples were not tested the first year. The curve shows that Black Amber cane maintains its germination for 15 years and then drops off rather rapidly. The fact that an increase of over 100% is shown for sorghum in Fig. 2 is due to a low germination of one crop the first year with a much higher germination the second year for two crops and thereafter. This may be due to some inherent factor in cane seed.

The data show that Rosen rye does not have the ability to maintain its viability like the other cereal grains studied. Four samples are represented in this test. From the curve in Fig. 2 it will be noted that rye drops off about 10% in the first 5 years and rather rapidly after that date. At 15 years the germination is low, and it reaches zero by the nineteenth year.

Wisconsin Black soybeans were used in the studies. They dropped off about 10% on the first 5-year period and by the fourteenth year had reached zero. The drop was exceedingly sharp after the sixth year. It may be interesting to note that as the beans dropped in germination indications of a break-down in the fat content was noted and reported from the germination test.

SUMMARY

Germination studies are reported on various farm crops stored for varying periods from 1 to 22 years. The crops were stored in sacks in a dry, unheated room.

The germination percentage of wheat, oats, and barley declined slowly for the first 10-year period. From the tenth to the fifteenth year wheat dropped 22.3%, oats 8.1%, and barley 7.7%. The drop was somewhat greater from the fifteenth to the twentieth year as follows: Wheat, 48.4%; oats, 24.4%; and barley, 39.5%. Twenty-one-year-old wheat germinated 12.8%, oats 49.6%, and barley 46.2% of the initial germination.

There were indications of varietal differences in germination between six-rowed hulled and two-rowed hulled and naked barley.

Rosen rye and Wisconsin Black soybeans did not maintain their viability after the first 5 years. They dropped to almost zero germination by the fifteenth year.

Black Amber cane maintained its germination for a 17-year period.

Yellow Dent corn gradually declined from the first to the twenty-first year, germinating 32% at the end of the period.

A dry, arid climate preserves germination in the farm crops studied so that stocks of wheat, oats, barley, sorghum, and corn can be stored for 20 years and still have enough viable seeds to maintain the stocks.

THE INTERRELATIONSHIPS OF SALT CONCENTRATION AND SOIL MOISTURE CONTENT WITH THE GROWTH OF BEANS[1]

A. D. AYERS, C. H. WADLEIGH, AND O. C. MAGISTAD[2]

THE effect of various soil moisture treatments upon plant growth is of particular interest to the grower of crops on saline soils for it is possible that differences in soil moisture may either decrease or intensify the salt effect.

Even when no harmful concentrations of salt occur in the soil, there is a diversity of opinion as to the proper time to irrigate to get the best growth. The individual farmer follows a practice which he feels is best suited to his conditions and to the crop he is growing. It is the custom in many localities, for instance, to irrigate potatoes, lettuce, and other truck crops far more frequently than would be necessary on the basis of the amount of water used by the plants.

Veihmeyer (21),[3] Hendrickson and Veihmeyer (11, 12), and Conrad and Veihmeyer (3) concluded from their experiments that as long as the soil moisture was above the permanent wilting percentage moisture was available to the plant and that any fluctuations between field capacity and the permanent wilting percentage would not be reflected in fruit yield or amount of growth.

Results published by Aldrich, *et al.* (1) indicated that whenever the average soil moisture in the first 3 feet fell below 70% of the available capacity on a clay adobe soil, the rate of growth of the pear fruits was reduced. They point out, however, that their results were conditioned by the difficulty of roots in permeating this heavy soil and by the rate of moisture movement through such a soil.

Davis (4), growing nut grass in 1-gallon pots of soil at five different irrigation schedules, found that growth was reduced if the soils were allowed to dry below the moisture equivalent before they were re-wetted.

The best results with spring lettuce in Arizona were obtained by Schwalen and Wharton (20) when the soil was kept relatively moist up until the harvest period.

The relation of plant growth to variation in the available soil moisture is further complicated in those soils which contain harmful quantities of salts. As such a soil drys out, the concentration of salts in the soil solution increases. The concentration of salts in the soil solution of a soil which is at the permanent wilting percentage would be much greater than that of the same soil when only a fourth or a half of its available moisture had been utilized. These differences might easily be reflected by differences in plant growth. In other words, a plant might grow better in a saline soil which is irrigated when only

[1]Contribution from the U. S. Regional Salinity Laboratory, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Riverside, Calif., in cooperation with the 11 western states and the Territory of Hawaii. Received for publication April 5, 1943.

[2]Assistant Chemist, Senior Chemist, and Director, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 809.

part of the available moisture has been utilized than in a similar soil in which the soil moisture is allowed to approach the permanent wilting percentage before irrigation takes place.

The material presented in this paper bears upon this complex question of soil moisture relations and plant growth in soils containing appreciable amounts of salts.

METHODS AND MATERIALS

Thirty-six 10-gallon steel drums were each filled with 102 pounds of surface soil from a location on the grounds of the Salinity Laboratory, Riverside, Calif. This soil was mapped as Sierra loam in an early survey but probably would be designated now as Fallbrook loam. As determined by the method proposed by Richards and Weaver (18), this soil held 6.2% moisture when moistened and allowed to come to equilibrium under a tension of 15 atmospheres. This 15-atmosphere value has been shown by Richards and Weaver to be in the wilting range. The permanent wilting percentage determined with sunflower plants was 6.1 and agrees closely with the 15-atmosphere value. The moisture equivalent was 14.7%. The saturated soil paste of the original soil had a pH of 7.6. At the conclusion of the experiment the soil pH values ranged from 6.6 to 8.0, depending upon treatment and the depth at which the sample was taken. Calcium was the predominating cation in the exchange complex at the start of the experiment, and there were no accumulated soluble salts in the original soil.

EXPERIMENTAL DESIGN

The experimental variables were four salt treatments, *viz.*, no added NaCl, 1,000 p.p.m. added NaCl on dry soil basis, 2,000 p.p.m. added NaCl on dry soil basis, and 4,000 p.p.m. added NaCl on dry soil basis; and three irrigation schedules. These schedules were as follows:

A low tension series, irrigated when only small amounts of the available moisture had been utilized by the plants as explained later; a medium tension series, irrigated when moderate amounts of the available moisture had been utilized by the plants; and a high tension series, irrigated when the plants showed severe moisture stress.

The 36 drums were divided into three blocks. This gave one drum of each combination of salt and irrigation schedule per block.

The screened (¼ inch) soil was mixed in an eccentric box with the proper amount of salts for each treatment. Besides the designated sodium chloride, 3.4 grams of potassium chloride and 10.1 grams of 18% superphosphate were added to each drum of soil. One hundred and seven pounds of the soil at a moisture content of 5% were placed in each container with the aid of a mechanical mixer and packer. Nitrate was supplied by scratching 11.3 grams of sodium nitrate into the soil surface of each drum just before the initial irrigation. These amounts of fertilizing materials corresponded to an application of 1,000 pounds of 6–8–6 fertilizer per acre.

Tensiometers were placed at depths of 4 inches and at 15 inches (bottom) of each drum in one block. Enough tap water[4] was added to bring the soil to an average moisture content of 20%. This amount wet the soil above the moisture

[4]The Riverside tap water used in this experiment is a very good quality of irrigation water. It contains only 270 p.p.m. of dissolved salts (cations 45% sodium).

equivalent but did not give any free drainage. The drums were weighed daily and when the moisture content reached a designated degree of depletion, sufficient tap water was added to reestablish the 20% level.

On January 31, 1942, after the irrigated soils had been standing for several days, six germinated dwarf red kidney beans were placed in each pot. When the seedlings were well established, they were thinned to the three most uniform in each container.

Red kidney bean plants were selected for this experiment because of (a) their high sensitivity to soil salinity, (b) their rapidity in completing the reproductive cycle, and (c) their relatively small size which permitted an equable relationship between plant size and the 10-gallons of soil used in each culture.

MOISTURE TENSION AND TIME OF IRRIGATION

The plants maintained under low soil moisture tension conditions were watered when the soil moisture tension at the 4-inch depth reached 250 cm of water. This was found to correspond to an average moisture content of 15% for all the soil in the container, and all pots in this moisture series were watered when the moisture percentage dropped to this value. Soil-moisture tension readings taken at the bottom of the soil columns were usually lower than those taken 4 inches below the surface, but never indicated any excessive concentration of moisture. (Tensions were always greater than 50 cm of H_2O.) The group of plants in the medium tension series was allowed to withdraw moisture from the soil until the tensiometers at the 4-inch depth registered a soil moisture tension of 750 cm of water.[5] This corresponded to an average moisture content of 11%. A third group of plants—high tension series—was not watered until the plants were appreciably wilted by mid-morning. These plants were turgid at sunrise and always recovered after irrigation. Only in those drums in which no added sodium chloride was present did the plants dry the entire soil mass to a degree approaching the 15 atmosphere percentage (6.2) which is within the wilting range. By observation of plant response and soil moisture percentages it was found that the plants wilted by mid-morning when the average moisture content of the entire soil mass was reduced to the following approximate figures:

Treatment, p.p.m. NaCl	Average moisture, %
0	7.5
1,000	9.0
2,000	9.5
4,000	10.0

At this time the tensiometer readings at the 4-inch depth in all soil treatments were "off scale"[6] and in the "O" NaCl group the tensiometers at the bottom of the drum were also off scale.

When the beans were fully matured (April 8, 1942), the fruits were picked, weighed, counted, and photographed. The soil was sampled by taking portions from each third of the container according to depth. The top third was designated

[5]Tension or negative pressure is here measured by the height of the column of mercury or water which it supports.

[6]Tensiometer readings much above 800 cm of H_2O are not considered accurate and the scale used to measure tensions is not graduated past 850. Further, the water column between the porous cup and the mercury manometer usually breaks near this latter tension range.

as 1/3, the middle third as 2/3, and the bottom third as 3/3. Specific electrical conductance determinations were made on the saturated soil paste from these samples.

RESULTS

Differences in treatment resulted in differences in the growth response of the plants and modifications in the physical and chemical characteristics of the soil. Trends in plant growth differences were evidenced early in the experiment and became more marked with time.

Representative pots from each treatment at the time of maximum growth are shown in Fig. 1. Increased additions of sodium chloride to the soil progressively reduced plant growth. In pots having the same salt content, growth was greatest in the pots irrigated most fre-

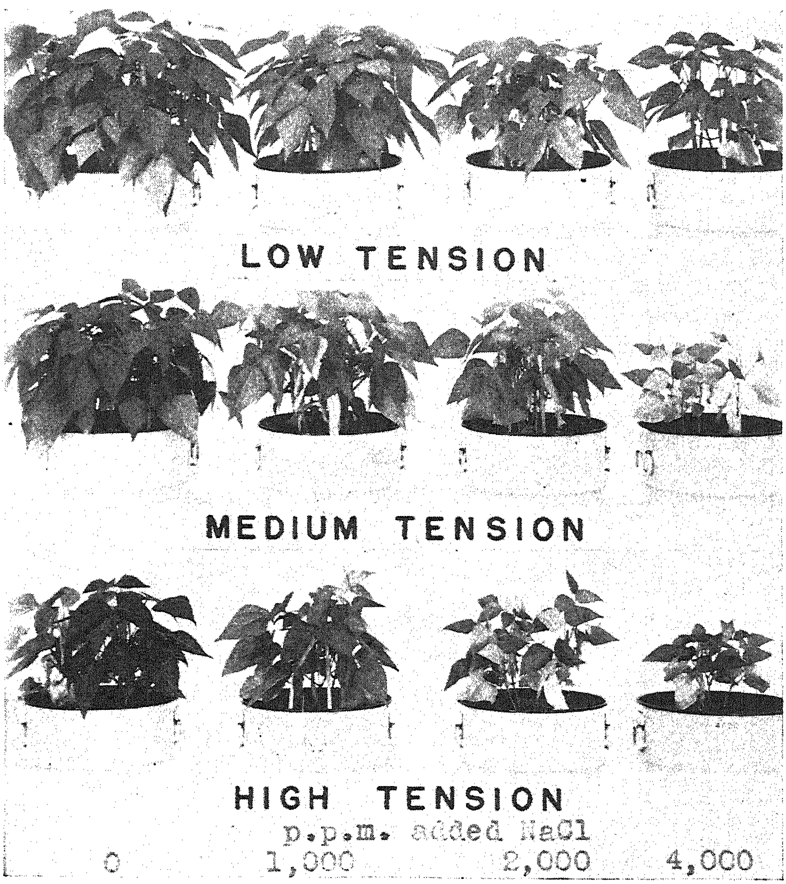

FIG. 1.—Growth of beans at four salt levels and irrigated at three soil moisture tensions.

quently and hence maintained at the lowest tension and was poorest in the pots receiving the fewest irrigations.

The plant responses to different treatments were reflected in fruit yields as well as in vegetative growth. The average number of pods, number of beans, and weight of the beans in grams per pot is given in Table 1. Actual beans harvested from the triplicate pots are shown in Fig. 2.

Table 2 presents the F values for the various sources of induced

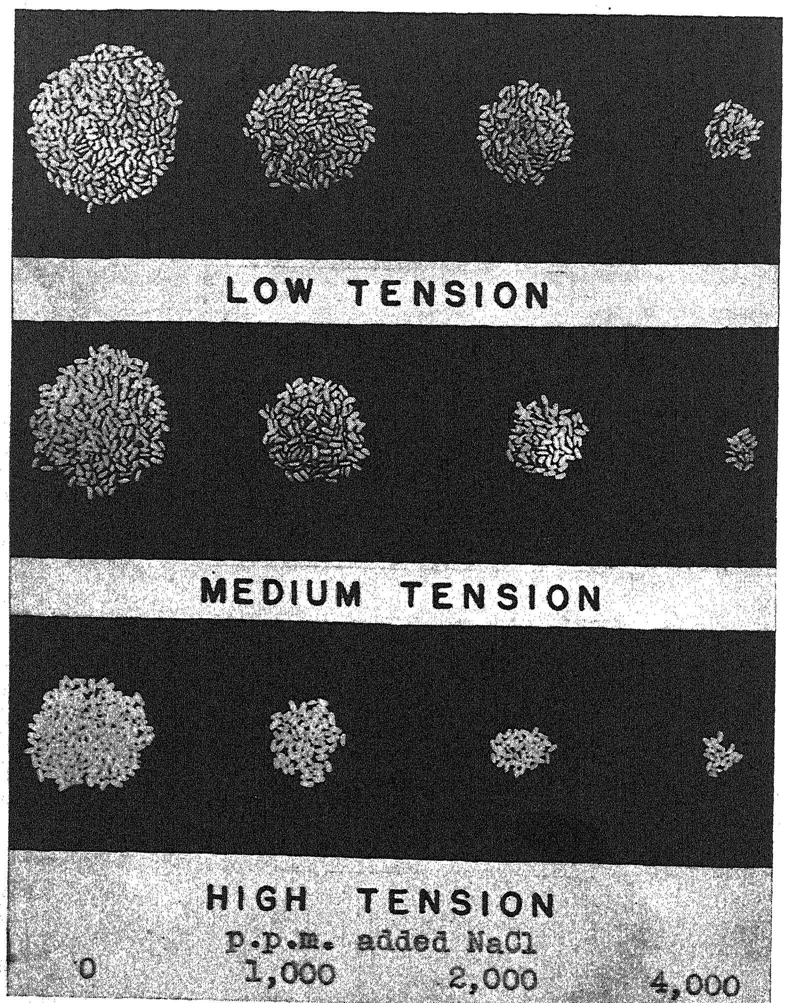

FIG. 2.—Yield of beans grown at four salt levels and irrigated at three soil moisture tensions.

variations upon the yield of beans per pot as well as the standard error and coefficient of variation.

TABLE 1.—*Average yield of beans per pot.*

Added NaCl, p.p.m.	Tension at time of irrigation								
	Low			Medium			High		
	No. of pods	No. of beans	Grams of beans	No. of pods	No. of beans	Grams of beans	No. of pods	No. of beans	Grams of beans
0	38.7	164.0	81.2	29.7	116.3	59.5	18.0	59.0	33.2
1,000	23.0	84.0	36.6	15.0	50.7	24.4	7.7	20.0	9.9
2,000	14.0	50.0	20.0	9.0	28.7	12.2	5.7	12.7	4.2
4,000	6.7	16.0	5.6	4.0	5.7	2.0	3.3	5.3	1.8

TABLE 2.—*F values for weight of beans per pot.**

T_1 low tension − high tension	384.25**
T_2 low tension + high tension − 2 medium tension	0.18
S_1 0 NaCl − 1,000 NaCl	612.13**
S_2 2,000 NaCl − 4,000 NaCl	42.50**
S_3 (0 + 1,000 NaCl) − (2,000 NaCl + 4,000 NaCl)	1142.83**
T_1S_1	39.17**
T_1S_2	12.47**
T_1S_3	130.99**
T_2S_1	0.16
T_2S_2	0.35
T_2S_3	1.42
Standard error	0.627
Coefficient of variation	12.14%

*Induced effects were segregated according to a single degree of freedom analysis (22). A chi square test of individual error terms indicated their homogeniety and the validity of using a pooled error term.
**Highly significant.

Distribution of the salts within the potted soils at the end of the experiment is indicated by specific electrical conductance measurements made on the saturated soil paste. These measurements are summarized graphically in Fig. 3.

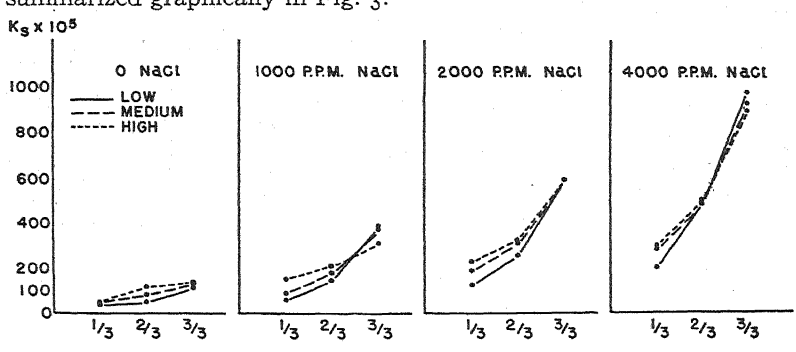

FIG. 3.—Conductance of saturated soil paste at 25° C.

Effect of treatment upon rate of growth and characteristics of fruit produced will be covered in a separate paper.

DISCUSSION

PLANT GROWTH IN THE "O" NaCl SERIES

As indicated in Figs. 1 and 2 and Table 1, the best growth and the highest yield of bean seeds were obtained in those containers which were maintained at low soil moisture tensions and to which no sodium chloride had been added. This treatment produced an average of 81 grams of beans per culture. Under the conditions of the medium moisture tension schedule, the vines produced an average of but 59 grams of beans per pot. This yield reduction occurred, although the plants were never wilted and there was always available moisture present. When irrigation was withheld from the plants until wilting[7] at mid-morning was in evidence (high moisture tension schedule), growth and yield were still further reduced. Under these conditions, each culture produced an average of only 33 grams of beans. The precision of this experiment was such (Table 2) that the above yield differences were well beyond the range required for high significance. Furthermore, the yield obtained from the medium tension pots was not significantly different from the mean of the low and high tension treatments. This is shown in Table 2 by the lack of a significant value for T_2.

The differences in yield obtained with the three irrigation schedules cannot be explained on the basis of root distribution. At the close of the experiment, examination showed that roots were well distributed throughout the entire soil mass in the "O" NaCl series. Increasing tensiometer readings also indicated that water was being removed from the lower depths as well as from the upper portions during the course of the experiment.

These reductions in the growth and yield of beans as the soils were allowed to dry to higher soil moisture tensions before being rewetted are in accord with the recent work of Davis (4) on nut grass. Previously, Furr and Taylor (7) and Aldrich, *et al.* (1) showed that with decreasing soil moisture the growth rate of lemon and pear fruits was retarded before the average soil moisture content reached the wilting range. Schneider and Childers (19) observed marked reductions in apparent photosynthesis and transpiration and an increase in respiration before wilting was evident in young apple leaves.

On the other hand, Veihmeyer (21), Conrad and Veihmeyer (3), and Hendricks and Veihmeyer (11, 12) found no decrease in plant growth under the conditions of their experiments as long as the soil was above the wilting point. Conrad and Veihmeyer (3) held that

[7]It is more difficult to describe the wilting of beans than of many common plants. The leaves of succulent plants with adequate water supply but suddenly subjected to a high transpirational stress will droop markedly in the conventional manner. However, plants which are gradually subjected to water stress respond by orienting their leaves parallel to the sun's rays and by inversion of the leaves. Actual drooping is not prevalent except on some of the oldest leaves. This latter type of response by the plant is referred to in this paper as "evidence of wilting".

even though the greater amount of roots or absorbing surface was in the top dry layers, roots in the deeper layers could absorb enough moisture to satisfy the needs of the plant, except under conditions of high evaporation.

In studying the daily growth of maize, Loomis (14) observed that direct sunlight inhibited the extension of the young leaf and attributed this to a temporary water stress brought about within the plant by the sunlight. A comparison of the leaf extension of a plant growing in moist soil and one growing in a relatively dry soil but still above the permanent wilting percentage, pointed to a higher average growth rate and longer growing period under the moist condition. Loomis found that the plant in the drier soil did not grow during the afternoon but did grow during the night. Apparently the growth of maize depends upon a liberal supply of water in the growing region. Sunlight, low relative humidity, and low soil moisture may check this growth by creating a moisture stress within the plant. This same sort of mechanism may influence the growth of beans and other plants.

When plants are unable to exert forces of sufficient magnitude to get water from the soil at a rate necessary to satisfy their needs, the plants wilt and death may be the final result. During this drying out process of the soil, the osmotic concentration of the plant sap increases (8, 13). This increase in the osmotic concentration of the plant sap, the decreased growth rate of lemon (7) and pear (1) fruits, and the reduction in photosynthesis and transpiration in apple leaves (19) as the soil moisture approaches but is not yet within the wilting range, indicate that increased water stresses are occurring within the plant as the soils become progressively drier.

A group of plants growing in moderately or partly dry soil will be under some water stress and, according to Loomis' theory, should have their growth retarded during periods of direct sunlight. Similar plants growing in moist soil should have less of an initial moisture stress and should therefore have shorter and less frequent periods of reduced growth and a faster growth rate. Other things being equal, the group of plants having the longest periods of actual growth and the highest rate should make the most growth. This reasoning could account for differences in growth between the low and medium moisture tension series.

PLANT GROWTH IN THE 1,000, 2,000, AND 4,000 P.P.M. NaCl SERIES

Presence of added amounts of NaCl in the soil reduced growth. This was shown in Figs. 1 and 2 and Tables 1 and 2. F values for S_1, S_2, and S_3 indicate the reductions in the weight of beans produced to be highly significant. If the bean yield in the best treatment, no added NaCl at low soil moisture tension, is taken as 100 and if the other yields are plotted as a percentage of this figure, total relative yields are obtained as shown in Fig. 4. Besides the effect of NaCl, this graph demonstrates the relationship between yield and soil moisture tension at time of irrigation under the conditions of this experiment.

Breazeale (2), Eaton (6), Magistad, *et al.* (15), and others have correlated plant growth in culture solutions with the excessive con-

centration of salts in the solution. The concentration of salts in the soil solution in contact with and surrounding the plant roots plays a similar role in the soil. Breazeale (2) recognized this when he suggested that salts in the soil should be reported on the basis of the moisture content of the soil at the wilting point rather than as a percentage of the dry weight of the soil. Conductivity measurements of the saturated soil (Fig. 3) give a relative measure of the expected concentrations of these soil solutions. The actual magnitude of these concentrations for several selected samples is shown in Table 3, together with the calculated changes occurring in concentration as the soil dries from a percentage slightly above the "field capacity" to a point where plants in the nonsaline soil begin to wilt. Solutions were extracted from these soils at approximately 12% moisture by the

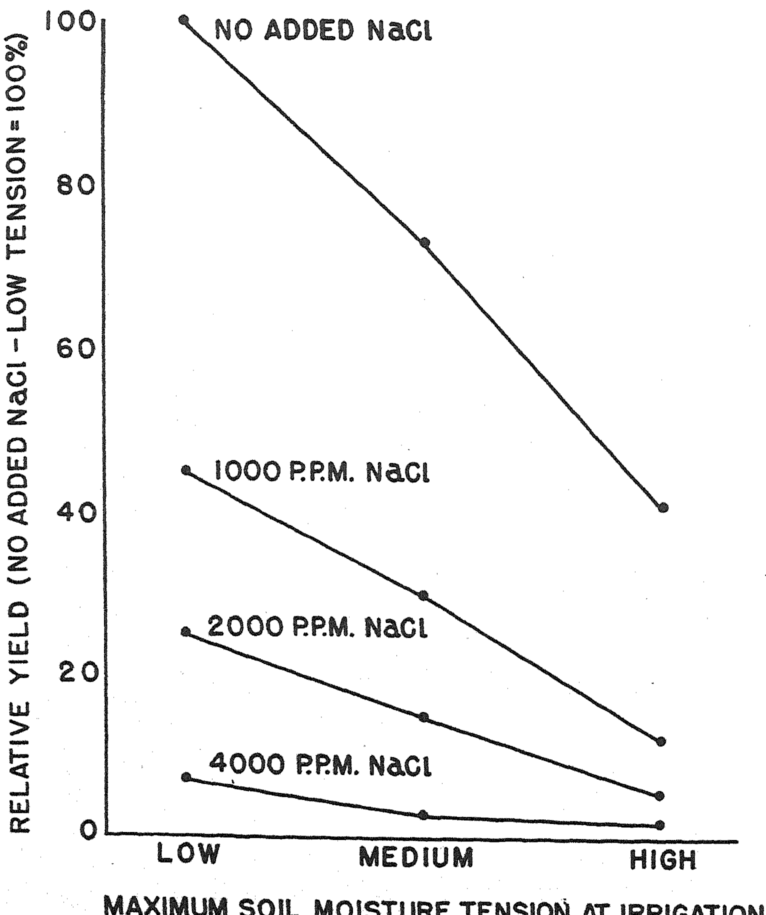

FIG. 4.—Relative yield of bean plants as conditioned by the various experimental treatments.

TABLE 3.—*Concentration of soil solution at close of experiment.*

Added NaCl, p.p.m.*	Depth, inches	Conductance soil paste, $K_s \times 10^5$@25°C†	Soil moisture, %	Conductance soil solution, $K \times 10^5$@25°C	Concentration soil solution, atmosphere‡	Calculated concentration of soil solution at four soil moisture percentages, atmos.§			
						7%	11%	15%	20%
0	0–5	51	11.27	284	1.04	1.67	1.07	0.78	0.59
0	5–10	86	11.35	630	2.63	4.26	2.71	1.99	1.49
0	10–15	122	11.02	1,075	3.55	5.59	3.56	2.61	1.96
1,000	0–5	92	11.71	711	2.64	4.41	2.81	2.06	1.55
1,000	5–10	199	12.56	1,800	7.00	12.6	7.99	5.86	4.40
1,000	10–15	369	12.57	3,480	14.3	25.7	16.3	12.0	8.99
2,000	0–5	165	12.84	1,405	5.34	9.80	6.23	4.57	3.43
2,000	5–10	305	12.96	2,840	11.08	20.5	13.1	9.57	7.18
2,000	10–15	574	12.82	5,540	23.31	42.7	27.2	19.9	14.9
4,000	0–5	271	11.64	2,560	11.3	18.8	12.0	8.77	6.58
4,000	5–10	494	11.98	4,260	19.9	34.0	21.7	15.9	11.9
4,000	10–15	915	11.94	8,590	50.4	86.0	54.7	40.1	30.1

*All samples from medium tension series.
†Saturated soil paste contained 37% moisture.
‡Osmotic concentration of solution in atmospheres calculated from freezing point depression.
§Values calculated assuming only simple dilution or concentration.

pressure-membrane apparatus described by Richards (16) and concentrations at the other moisture contents calculated. Obviously, there is a tremendous change in concentration as the soils dry.

In order to show the effect of the moisture treatment in the presence of salts, the bean yields were recalculated on a relative basis using the yield of the low moisture tension treatment for each salt level as 100. Averages of the three replications are plotted in Fig. 5. The slopes of these curves show that when salts were present in the soil, increasing the soil moisture tension at the time of irrigation increased the severity of the salt treatment.

The reasoning that growth differences in soils at several moisture contents above the permanent wilting percentage may be due to

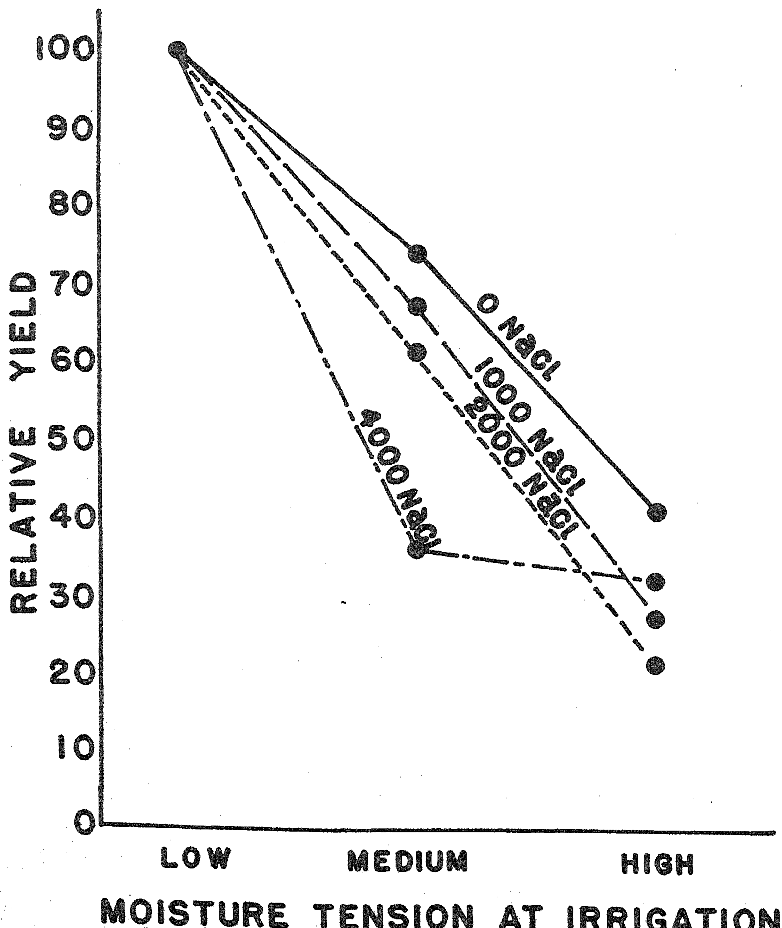

FIG. 5.—Relative yield of beans grown at four salt levels and irrigated at three soil moisture tensions using the yield at the low moisture tension at each salt level as 100.

water stresses affecting the total time and rate of actual growth is also applicable to the growth of plants in soils containing added NaCl. Decreased relative yields in the saline soils irrigated at increasing soil moisture tensions may be a reflection of the water stresses produced in the plant under these conditions.

OSMOTIC EFFECT OF SOIL SOLUTION

With respect to the energy relations, more work is required to remove a gram of water from a solution as its concentration increases. Plants growing in saline soils must then do more work to obtain a given amount of water than plants growing in a less concentrated soil solution. Moisture treatments will affect the concentration of this soil solution. As shown in Table 3, soils which are allowed to dry to a point just above the wilting range will have for considerable periods of time a much more concentrated soil solution than similar soils which are kept relatively moist. In substantiation of the osmotic effect of the soil solution, Eaton (5) has brought out the fact that roots absorb more water from dilute than from the more concentrated solutions.

It is noteworthy that the soil to which no sodium chloride had been added revealed very significant osmotic concentrations of the soil solution. These concentrations arose mainly from the moderately heavy application of fertilizing materials. In the cultures in which the moisture content of the soil became low, it is evident that the concentration of the soil solution was sufficient to be definitely inhibitive to the growth of beans (15). This situation was unquestionably involved in the growth decreases accompanying the increased degree of soil moisture depletion prior to irrigation. Nevertheless, it should be emphasized that the yield of the plants in the cultures with 1,000 p.p.m. of added salt in the low tension series was higher than that from the "no salt" cultures of high tension series, even though the osmotic concentrations of these soil solutions within their respective limits of soil moisture content was just the reverse. This is shown as follows:

	High tension, no salt	Low tension, 1,000 p.p.m. salt
Grams of beans	33.2	36.6
Osmotic concentration of soil solution at:		
0–5 in.	1.67	2.06
5–10 in.	4.26	5.86
10–15 in.	5.59	12.0

The above observations suggest that far more attention should be given to osmotic relationship of soil solutions in non-saline as well as in saline soils. It would seem that particular study should be made of osmotic concentrations occurring when large fertilizer applications are made to heavy soils, and of the effect of such conditions on plant growth, apart from the plant food effect.

EXTENSION OF ROOTS INTO NEW SOIL AREAS

The inhibiting action of concentrated soil solutions upon the extension of the plant root system into new soil areas may be even more important than the direct osmotic effect upon water absorption. Movement of water from unsaturated moist soil into dry soil is extremely slow. If the roots do not grow into new soil masses, water absorption is limited to areas already occupied by these roots and this available moisture may be quickly utilized. In the case of annual plants and rapidly growing young perennials, the extension of the root system is imperative for continued vigorous growth from the standpoint of the rate of absorption of both water and nutrients.

Eaton (5) showed that concentrated salt solutions definitely retard root growth. Additions of NaCl to soil in this experiment limited root distribution. This was evidenced from excavations made at the conclusion of the experiment as shown in Table 4, and from soil moisture tension measurements made in the pot during the growth period.

TABLE 4.—*Approximate depth of root penetration in inches.*

Added NaCl, p.p.m.	Soil moisture tension at time of irrigation		
	Low	Medium	High
0	15*	15	15
1,000	12	11	10
2,000	9	8	8
4,000	8	7	6

*Total depth of soil 15 inches.

DECREASED ABSORPTIVE CAPACITY OF ROOTS

High concentrations of salts in the soil solution which limit root growth may affect moisture absorption by plants in still another manner. Maximum moisture absorption occurs just back of the root tip in the area where elongation is taking place and secondary thickening has not yet started (10). Roots in concentrated salt solutions grow slowly (5), becoming quickly suberized and having little rapidly absorbing root area (5, 9). Any factor, such as moisture level or the addition of NaCl, which affects the concentration of the soil solution will affect the amount of new roots being produced. Other things being equal, plants with a high percentage of young, rapidly absorbing roots should be able to take up water at a faster rate than plants having an equal amount of older roots.

Many factors undoubtedly play important roles in the effect of salts upon growth of plants in soils. It is not intended that climate, leaching, aeration, soil structure, soil reaction, direct toxicity of specific ions, and other effects be overlooked or minimized; but consideration should also be given to the part played by moisture stresses within the plant and the soil-root relationships which may affect these stresses. Relationships which should not be overlooked include (a) the increased work necessary to obtain water from the soil as the

soil moisture tension increases; (b) the increased work necessary to obtain water from the soil solution as the osmotic concentration of the soil solution is increased; (c) the inability of the plant roots to grow into areas of undepleted soil moisture because of the presence of high concentrations of salts in these areas; and (d) the inability of the plant to produce new roots having a maximum absorptive capacity because of the presence of high concentrations of salts in the soil solution. Each of these factors may be affected directly or indirectly by the frequency of irrigation and may have a bearing upon irrigation practice in saline soils.

SUMMARY

Dwarf red kidney beans were grown to maturity in 10-gallon containers filled with loam soil. These soils contained 0, 1,000, 2,000, and 4,000 p.p.m. of added sodium chloride on the dry soil basis. The 36 containers were divided into three moisture tension series. Water was added when the soil moisture tension at the 4-inch depth had reached 250 cm of water and 750 cm of water for the first two series, respectively. Water was added to the third series when the plants were wilted by mid-morning, corresponding to tensions exceeding 800 cm of water.

Bean growth and yield were reduced as the soil moisture tension at time of irrigation increased, even though in some of the treatments the soil moisture was always above the wilting range.

Progressive additions of sodium chloride to the soil caused progressive decreases in growth and yield of beans.

The relative effect of sodium chloride on the reduction in yield of bean fruits was greater in those treatments in which the soil moisture tensions were greater at the time of irrigation.

Attention is called to a consideration of moisture stresses within the plant in relation to growth and to certain factors which may affect these stresses.

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GRASSES FERTILIZED WITH NITROGEN COMPARED WITH LEGUMES FOR HAY AND PASTURE[1]

B. A. Brown and R. I. Munsell[2]

When the war ends, some of the products of the synthetic nitrogen factories may be available for purposes other than munitions. For some time this question has been under study by a joint committee of the American Society of Agronomy, the American Society for Horticultural Science, the Association of Land-Grant Colleges and Universities, the National Fertilizer Association, the Tennessee Valley Authority, and the U. S. Dept. of Agriculture. The general idea appears to be that if nitrogen in fertilizers should be relatively cheaper than before the war, it might be a good policy for farmers to increase their use of this important plant nutrient.

For many years, the Agronomy Department of the Storrs, Conn., Agricultural Experiment Station has had hundreds of plots on which the response of grasses to various rates and times of application of nitrogenous fertilizers has been determined. On the same field and during the same seasons, legumes and legume-grass mixtures have been under test. It is the purpose of this paper to present the many data now available on these comparisons. All of the experiments were located at or near Storrs, on Charlton fine sandy loam soil, which, because of its compact subsoil, retains water relatively well and is therefore one of the best soil types in Connecticut for the growth of grasses.

TIMOTHY FOR HAY

Timothy is the chief grass grown for hay in the hay-dairy belt of North America. Usually it is seeded with red clover, but after the second season, the clover is largely gone and the growth of the timothy is retarded for lack of nitrogen, unless topdressed with manure or nitrogenous fertilizers. To learn what changes in quantity and quality of hay could be obtained with nitrogen and different dates of cutting, a 1931 seeding of red clover and timothy was divided in 1933 into duplicated, 100×10 foot plots which were fertilized and mowed as outlined in Table 1. By 1938, the stand of timothy had become considerably mixed with other grasses, so the field was plowed and reseeded to timothy and a similar experiment continued through 1941. The pertinent results for the period of 1939–41 are presented in Table 2. For comparison, the yields of alfalfa from nearby plots and during the same years are included in Table 1 and yields of Ladino mixtures in Table 2.

It is apparent that the added nitrogen was responsible for marked increases in yields of both dry matter and protein from the timothy in the 5-year period 1933–37. If not cut *before June 15*, each of the two 28-pound increments of nitrogen enhanced the dry matter by 900 to 1,200 pounds. It will be noted, however, that the protein

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yields from the first cuttings remained practically constant for any given fertilizer treatment from June 1 to June 30. This was due to the declining percentage of protein with the increasing percentage of carbohydrates, as the timothy became more mature. Fiber increased from about 22 to 32% during the month of June. Even where nitrogen at 56 pounds was applied, the grass in the first cutting had absorbed the maximum amount by June 1. Fertilizer nitrogen at either 28 or 56 pounds caused greater growth but did not raise the percentage of protein. In this respect, the date of cutting was very important, as may be judged by the fact that on June 1 the protein content was 12%; on June 15, 9%; and on June 30, 7%. Protein is emphasized, not because animal rations cannot be balanced economically with oil meals, etc., but because usually there is a close correlation between protein and several other animal nutrients which indicate improved quality, like fat (ether extract) and the essential minerals.

TABLE 1.—*The effects of nitrogen and dates of cutting on the yields of timothy, 1933–37.**

Nitrogen applied, pounds per acre†	First cutting on			Second cutting following first cutting on			Totals if first cutting on		
	June 1	June 15	June 30	June 1	June 15	June 30	June 1	June 15	June 30
	Dry Matter, Cwts. per Acre								
None	10	16	23	8	4	4	18	20	27
28 in April	20	29	35	7	4	3	27	33	38
28 in April; 28 in June	20	31	35	16	9	5	36	40	40
56 in April	25	39	46	6	5	4	31	44	50
None; alfalfa, 2 cuttings in medium bloom stage	—	—	—	—	—	—	—	56	—
	Protein, Pounds per Acre								
None	128	161	181	88	50	50	216	211	231
28 in April	248	240	237	85	48	46	333	288	283
28 in April, 28 in June	242	271	228	127	111	74	388	383	302
56 in April	341	348	335	74	62	59	414	410	394
None; alfalfa, 2 cuttings in medium bloom stage	—	—	—	—	—	—	—	840‡	—

*At Storrs timothy is in bloom the last part of June. The dates of second cuttings varied in some years; not in others.
†June N was applied *after* the first cutting.
‡The alfalfa was not analyzed in those years, so used one of the lowest percentages (15%) ever found in alfalfa at Storrs for calculating the yield of protein.

When June 15 was the date of first cutting and a second application of nitrogen was added soon afterwards, a *total* yield of fair weight and quality was obtained. This system produced 4,000 pounds of dry matter and nearly 400 pounds of protein. An additional 1,000 pounds of dry matter but no more protein resulted from applying 56 pounds of nitrogen in April and postponing the first cutting to June 30. In the same seasons, however, alfalfa cut two times per season and not fertilized at all after seeding, produced 40 and 12% more dry matter than the timothy cut first on June 15 and June 30, respectively, and

over twice as much protein as the timothy in *any* of the various fertilizer-cutting systems. It should be pointed out that the alfalfa in question was not analyzed and so one of the lowest percentages of protein every found in alfalfa at Storrs was used for the calculation of yield of protein. The lowest yield of protein from similarly cut alfalfa in another experiment during 1934 and 1935 was over 1,000 pounds per acre.

The 1939–41 results with the reseeded timothy are compared with the averages of five Ladino-grass mixtures, also seeded in 1938. This comparison is made because many farmers do not treat their soils and manage their crops so as to succeed with alfalfa. Ladino clover is a perennial legume that will thrive under soil conditions satisfactory for *good* results with timothy. For best results, however, Ladino-grass mixtures should be cut three times per season, at least. The data presented in Table 2 are from plots cut four times each year. The fourth, or October cutting, yields much less than the others and could be omitted or grazed without detracting greatly from the total production of hay.

TABLE 2.—*Comparison of timothy with Ladino-grass mixtures for hay, 1939–41.*

Nitrogen applied, pounds per acre	Crops and cuttings	Total pounds per acre	
		Dry matter	Protein
None................	Timothy (first cut June 12)	2,252	310
28 in April; 28 in June	Timothy (first cut June 12)	3,643	371
None................	Timothy (first cut June 29)	2,544	290
28 in April; 28 in June	Timothy (first cut June 29)	4,337	324
None................	Averages of five Ladino-grass mixtures cut four times per year	4,986	895

As may be seen in Table 2, nitrogen at 28 pounds in April and again in June increased the total dry matter yields of timothy about 1,400 pounds if the first cutting was June 12 and about 1,800 pounds if cut first on June 29. Because there was some volunteer white clover in the no-nitrogen plots, the use of fertilizer nitrogen resulted in only meager increases in the yield of protein. During the same seasons, the Ladino-grass mixtures averaged over one-third more dry matter than the timothy cut first on June 12 and one-sixth more than the timothy cut first on June 29. Moreover, the Ladino mixtures, with no fertilizer nitrogen, produced 141% more protein than the timothy to which was applied a total of 56 pounds of nitrogen each season.

KENTUCKY BLUEGRASS AND RHODE ISLAND BENT GRASS FOR PASTURES

These two species are the chief grasses in improved permanent pastures of northeastern United States. In August, 1935, pure seed-

ings of each grass were made on adjacent 100×50 foot blocks. In the early spring of 1936, duplicate 50×8 foot plots on each block of grass were seeded to Ladino clover without tillage. During that and subsequent seasons, other plots of these grasses received nitrogen, chiefly in calnitro, at 28 pounds in each of the months of April, June, and August. All plots were lawnmowed 4 inches to 1 inch, an average of eight times per season for 7 years. The seasonal and total yields of dry matter and the average percentages of protein are shown in Table 3. It may be stated briefly that with either grass alone, the effects of nitrogen at 84 pounds per season were not equal in quantity or quality of pasturage to seeding Ladino clover with the grasses. The only advantage of the pure grasses plus nitrogen was that this system produced larger yields than the combination of grass and clover during the first two weeks in May.

TABLE 3.—*Grasses plus Ladino clover versus grasses plus fertilizer nitrogen for pasture.**

Treatment	Dry matter, pounds per acre							Percentage protein†
	Before May 16	May 16–June 15	June 16–July 15	July 16–Aug. 15	Aug. 16–Sept. 15	After Sept. 15	Totals	
Rhode Island Bent Grass								
Grass plus Ladino..	380	701	615	673	479	198	3,046	23.7
Grass plus nitrogen.	502	700	567	448	445	157	2,819	21.3
Kentucky Bluegrass								
Grass plus Ladino..	473	788	592	698	462	203	3,216	24.3
Grass plus nitrogen.	579	674	626	464	447	137	2,927	21.0

*Results are averages of 1936 to 1942 on plots, lawnmowed eight times per season. Grasses were seeded in August, 1935, and Ladino clover added in March, 1936. Nitrogen was applied to grasses alone at 28 pounds in April, June, and August, or a total of 84 pounds per year.

†Values given are average protein contents in 1937, 1938, and 1939. The crops were not analyzed in other years.

NITROGEN ON PERMANENT PASTURES

The preceding discussion dealt with data obtained on tillable, seeded land, where it was possible to control to a considerable extent the species on the plots. For 10 years, 1932 to 1941, nitrogen was added at various dates and amounts to 7 of 17 2-acre, quantitatively grazed, permanent pastures. These pastures were grazed by yearling dairy heifers that received no supplemental feed. In Table 4 may be found a summary of the results.

All of the nitrogen plots produced larger *total* yields than the minerals plots. Most of the additional feed, due to nitrogen, grew in May and early June. This was especially true of the spring nitrogen plots. The least summer decline occurred on the pastures where nitrogen was withheld until June or August. The summer nitrogen, however, was much less effective in increasing growth than the spring treatments.

TABLE 4.—*Nitrogen and minerals versus minerals on permanent pastures.**

Nitrogen applied, pounds per acre		Total digestible nutrients, pounds per acre			
Rates and dates	Total per year	Before June 16	June16–Aug. 15	After Aug. 15	Total
28 in April	28	832	426	296	1,554
28 in April and June	56	957	511	328	1,796
28 in April, June, and August	84	975	510	360	1,845
56 in April	56	1,002	414	268	1,684
28 in June	28	567	487	301	1,355
28 in August	28	597	445	327	1,369
28 in June and August	56	782	524	348	1,654
Minerals only	0	614	422	211	1,247

*Results from grazed plots 1932 to 1941. Clover occupied about 6% of the area in the N plots; 15% in those treated with minerals only.

In May and June grasses decrease so rapidly in palatability and feeding value that it is imperative to graze them to capacity during those months in order to keep the herbage in a leafy condition. In this experiment the spring nitrogen plots produced only 29% of the feed necessary for their May-early June load of stock during the remainder of the season. The corresponding values for the other groups were as follows: For the spring plus summer nitrogen group, 33%; for the minerals only pastures, 39%; and for the summer nitrogen plots, 47%. In other words, the use of spring-applied nitrogen on pastures increased the acreage of supplementary pastures or other feeds necessary to carry the same number of animals throughout the season.

On smooth land, surplus May-June pasturage can be mowed for hay or silage, but many of the permanent pastures in northeastern United States are too rough or steep for machine mowing. Moreover, on most farms in this region there is a far greater acreage of land suitable only for permanent pasture than there is for seeded pasture and other crops. Permanent pastures are probably the cheapest source of feed for cattle. These data would seem to demonstrate that the improvement of larger areas of permanent pastures by adding the necessary minerals is a far better practice than intensive fertilization with both minerals and nitrogen of a smaller area. Even on farms with pastures smooth enough to permit machine mowing of surplus May-June feed stimulated by spring nitrogen, it would seem to be a better practice to till and seed leguminous mixtures, which, as shown by the values in Tables 1, 2 and 3, will produce larger total and better distributed yields of forage than grasses receiving heavy applications of nitrogen. Moreover, if legumes are neither grazed nor mowed at a definite time, they do not depreciate in feeding value nearly so rapidly as the grasses.

FERTILIZER NITROGEN ON LEGUMES

It has been stated by some that the nitrogen problem with forage crops is not a question of fertilizer nitrogen *or* legumes, but fertilizer

nitrogen *and* legumes. They suggest applying nitrogenous fertilizers to legumes as well as to grasses. The only data the Storrs Experiment Station has on this question are for nearly pure stands of alfalfa. With that crop, nitrate of soda applied at 125 pounds in April and repeated after the June cutting to 12 of 36 plots in 1934 and 1935 caused no significant differences in either protein content or yields of dry matter. Numerous tests with alfalfa have also shown that on well-limed and phosphated soils, the chief effect of stable manure is traceable to its content of potash. It has been observed many times that the heavy manuring of alfalfa resulted in severe lodging and the loss of most of the lower leaves.

In another experiment, the yields of some lawnmowed plots of turf grasses were not increased by applying nitrogen at 28 pounds in each of the months of April, June, and August when 40% or more of their areas were occupied by volunteer white clover.[3] In this case, as well as in other experiments at the Storrs Experiment Station, the nitrogen, chiefly from sulfate of ammonia, reduced markedly the prevalence of the clover and, of course, made it impossible to determine the yields of plots with both clover *and* fertilizer nitrogen.

SUMMARY

The yields and quality of several grasses fertilized with nitrogen for hay and pasture are compared with those from legumes and legume-grass mixtures.

During a 5-year period, the yields of timothy were increased markedly by 28 or 56 pounds of nitrogen per acre annually, but in the same seasons alfalfa on nearby plots, unfertilized since seeding, produced more dry matter and over twice as much protein.

Ladino clover-orchard grass seedings also yielded more dry matter and much more protein than another stand of timothy fertilized with 28 pounds of nitrogen in each of the months of April and June.

The seeding of Ladino clover with either Kentucky bluegrass or Rhode Island bent grass, lawnmowed eight times per season for 7 years, resulted in slightly larger *total* and better distributed yields than the application of nitrogen at 28 pounds in each of the months of April, June, and August on the grasses alone.

On grazed permanent pastures, spring-applied nitrogen stimulated a 30% increase in *total* yields over mineral fertilization. Most of the additional growth occurred before June 16. Spring and summer nitrogen resulted in less May but more summer feed than from applying all of the nitrogen in April. The most uniform seasonal distribution of pasturage was obtained by adding nitrogen only in the summer, but the returns per unit of nitrogen were about half those from the spring treatments.

[3]Storrs (Conn.) Agr. Exp. Sta. Bul. 209. 1936.

SOME EFFECTS OF THE WAXY GENE IN CORN ON PROPERTIES OF THE ENDOSPERM STARCH[1]

G. F. SPRAGUE, B. BRIMHALL, AND R. M. HIXON[2]

COLLINS (5)[3] and Kempton (9) have shown that the gene controlling waxy endosperm in maize is completely recessive to all other common types of endosperm, horny, flinty, pop, dent, starchy, etc., except the sugary type (6). When a plant having waxy kernels is crossed with a plant having starchy kernels, the hybrid kernels all have starchy endosperms regardless of whether the waxy plants are used as seed or pollen parent, and in the next generation segregation of the kernels occurs in agreement with the simple Mendelian ratio of 3 starchy to 1 waxy. The hard waxlike appearance of the waxy endosperm served as a ready means of identification in these experiments.

Parnell (10) reported similar observations with rice in which starchy is completely dominant over the waxy or glutinous condition. He differentiated the two kinds of kernels by their coloration with iodine, the former staining blue and the latter reddish-brown. The starch contained in the pollen grains exhibits the same color reaction with iodine as that contained in the endosperm. The pollen grains from homozygous starchy plants are blue-staining, those from waxy plants are red-staining, and those from a heterozygous plant are 50% blue-staining and 50% red-staining (4, 7, 10).

The present report deals with the properties of starches isolated from the endosperm genotypes Wx Wx Wx, Wx Wx wx, wx wx Wx, and wx wx wx, respectively, where Wx represents the starchy allel and wx the waxy allel. By the use of more sensitive criteria than endosperm texture or color with iodine, there was observed a distinct trend toward waxy properties in the starch as the proportion of waxy to starchy genes increased.

EXPERIMENTAL METHODS

Source of samples.—The grain used in these studies was obtained from two hybrids, Iowa 939 and waxy 939. Iowa 939 was one of the first hybrids released by the Iowa Experiment Station and is homozygous starchy. The waxy 939 has been produced by introducing the waxy gene into four inbred lines of Iowa 939 (I205, L289, Os420, Os426) by means of the backcrossing technic. The waxy strains of the lines had been backcrossed for four to six generations when com-

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[3]Figures in parenthesis refer to "Literature Cited", p. 822.

bined, so the analogous lines I205Wx, I205wx, etc., should be largely isogenic. Using these two double crosses, four different endosperm genotypes were produced as follows:

1. Iowa 939, sib-pollinated........................WxWxWx
2. Iowa 939 × waxy 939..........................WxWxwx
3. Waxy 939 × Iowa 939..........................wxwxWx
4. Waxy 939, sib-pollinated........................wxwxwx

Each of these four lots of grain was a mixture of the grain from at least 25 ears.

Milling.—The four samples of corn were milled at the same time under identical conditions in a small-scale wet-milling unit, the operation of which has been described elsewhere (8). Two and one-half pounds of grain from each sample were placed in cheesecloth bags and the four samples steeped together at 50° C in 5 gallons of water which at no time contained more than 0.2% SO_2. This procedure assured that the variation in viscosity of the starches described below was not caused by any differences in the milling operation.

Determination of amylose component present in the starch.—This procedure has been described by Bates, French, and Rundle (1) in which 0.04 gram of starch is dispersed in 10 ml of 0.5 N KOH solution, diluted with 85 ml distilled water, and neutralized with hydriodic acid using methyl orange indicator. It is then titrated potentiometrically with a solution of 0.001 N iodine in 0.05 N KI. The iodine is added in 1-ml portions, allowing 2½ minutes after each addition before reading the voltage. The end-point of the titration is taken at the inflection point of the curve in which voltage is plotted against ml of iodine added. The significance of this measurement is pointed out below.

Viscosity.—Three grams of starch (dry basis) in 100 ml of distilled water were heated 35 minutes in a water bath at 90° C. Viscosity was measured at that temperature with a straight-form capillary Ostwald pipette, under pressures of 13 and 23 cm (2).

Rigidity.—Five grams of starch in 100 ml of water were heated on a water bath at 98° C for ½ hour and the pastes poured into rigidity cylinders and allowed to set to a gel overnight at room temperature. Rigidity was measured by the method of Brimhall and Hixon (3) and is a quantitative measure of the strength or elasticity of the gel.

RESULTS

The differences in behavior between genetically pure non-waxy cornstarch, such as sample 1, Table 1, with its high gelling properties and relatively low viscosity, and pure waxy cornstarch, sample IV, Table 1, with extremely high viscosity and almost no tendency to set to a gel, have been described in previous publications (3, 8). Viscosity and rigidity measurements, therefore, provide excellent, sensitive means of detecting differences in "degree of waxiness" among starches.

When pastes of each are made up on the water bath, a difference between pure non-waxy and sample III (wx wx Wx) is evident merely by visual observation. The latter is somewhat more translucent and contains a greater number of tiny bubbles, characteristics which are shown by waxy starch pastes to a high degree. Table 1 clearly illustrates the increase in viscosity and decrease in rigidity or gelling tendency of the starches as the number of waxy genes in the endosperm increases.

TABLE 1.—*The relation between endosperm genotype and rigidity and viscosity properties of the endosperm starch.*

Starch No.	Genotype of endosperm	Rigidity Dynes/cm$^2 \times 10^{-1}$	Viscosity in centipoises	
			13 cm	23 cm
I	WxWxWx	222	24.4	16.5
II	WxWxwx	185	41.8	25.8
III	wxwxWx	61	66.6	33.4
IV	wxwxwx	0	490	230

An attempt was made, by mixing samples I and IV in known proportions, to get a paste approximating that of sample III in viscosity. It was found, however, that synthetic mixtures of non-waxy and waxy starch could not be made to duplicate the behavior of the starch milled from heterozygous wx wx Wx corn, since their viscosities decreased at different rates with increasing pressure, as shown in Fig. 1.

Another technic used to differentiate these starches, potentiometric titration with iodine, has a more sound theoretical basis than the

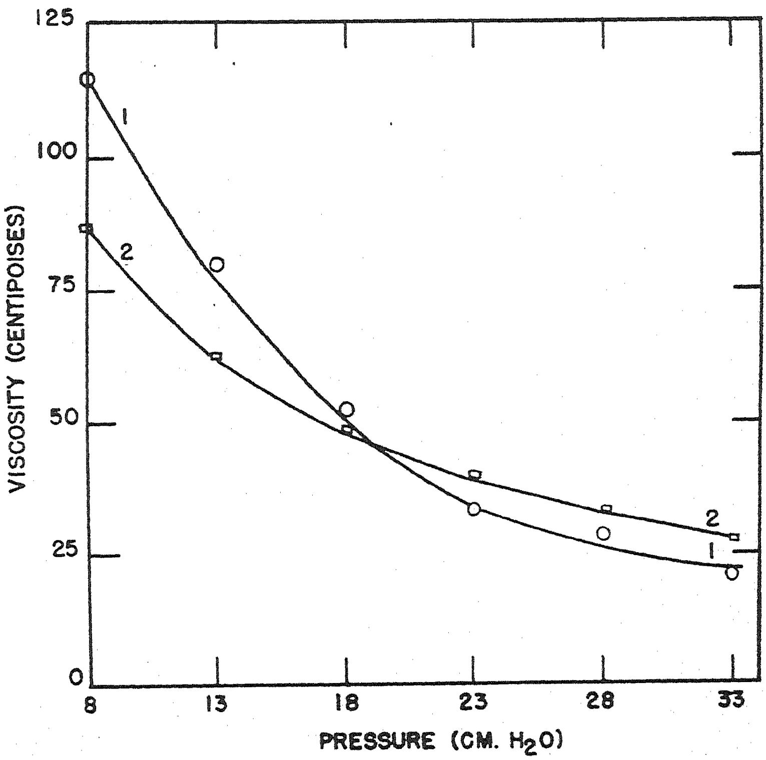

FIG. 1.—Viscosity-pressure curves for (1) non-waxy starch wxwxWx and (2) a mixture of 7 parts non-waxy with 1 part waxy starch. 3% pastes at 90° C.

foregoing methods. Most starches consist of two types of molecules, straight chain molecules, which make up the "amylose" fraction of starch and are responsible for its blue color with iodine, and branched molecules, which make up the "amylopectin" fraction and give only a red or red-brown iodine color. Ordinary cornstarch, like sample I, contains about 22% of the blue-staining constituent, or amylose, while waxy starch contains none at all, being 100% amylopectin.

Thus, all starches containing an appreciable amount of amylose will stain blue with iodine, and samples I, II, and III all appear to give the same blue color. However, by using a quantitative titration method like the above, differences can be detected easily, as shown in Fig. 2. Curves for samples II and III lie between those for pure non-waxy and pure waxy. In Table 2 are listed the relative percentages of amylose in the four samples as calculated from the curves in

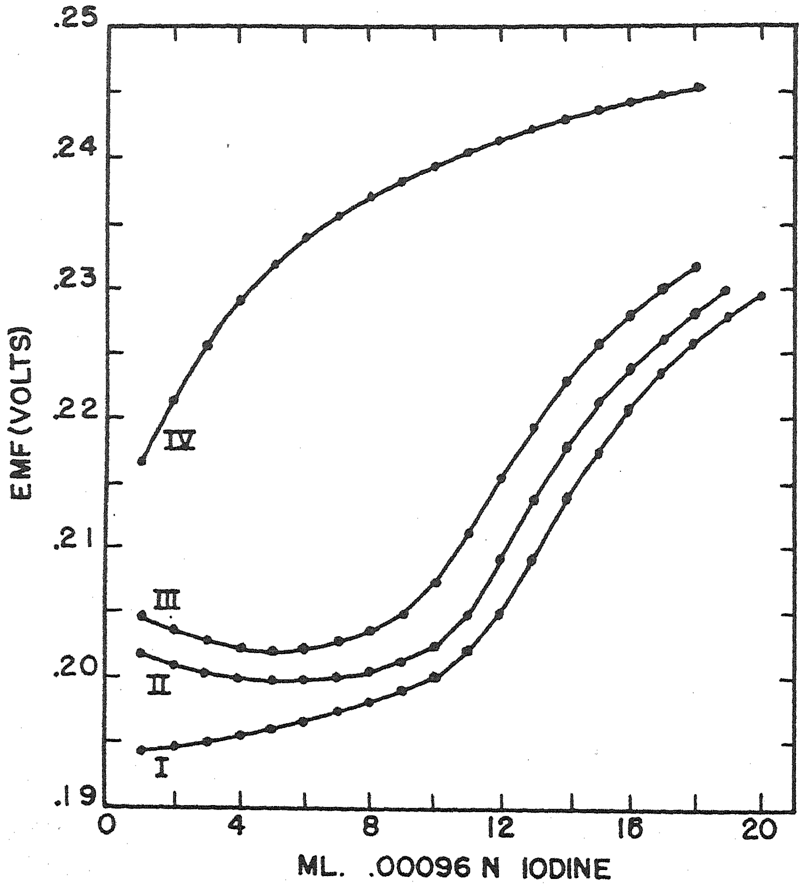

FIG. 2—Potentiometric titration curves for 0.04% solutions of starches. I, WxWxWx: II, WxWxwx; III, wxwxWx; IV, wxwxwx.

Fig. 2, along with the percentage of waxy starch which would have to be mixed with non-waxy starch to give identical titration curves.

TABLE 2.—*The relation between endosperm genotype and the percentage amylose of the endosperm starch.*

Sample No.	ml. 0.00096N iodine	Amylose in sample, %	Waxy required, %
I	13.75	22.0	0
II	12.75	20.4	7
III	11.50	18.4	16
IV	0	0	100

DISCUSSION

Although preliminary in nature, the foregoing results indicate that the waxy gene is not completely recessive in its influence as was previously believed. This is evidenced by the intermediate properties of the two heterozygous types, Wx Wx wx and wx wx Wx. Ignoring the completely recessive type, wx wx wx, the data on rigidity and viscosity indicate a simple additive type of factor action. The data on percentage amylose indicate a rather high degree of dominance.

The fact that it is possible to produce starches of intermediate character is not of immediate industrial value because of the additional expense which would be involved. For example, if it were desirable to produce a starch having viscosity and rigidity properties of the Wx Wx wx type, it would be necessary to produce the grain for milling in a detasseled crossing plat rather than in a regular commercial field.

The results promise to be of considerable theoretical interest, however, in studying the mechanism of starch synthesis in the kernel. They may provide an approach to the question of how the waxy allel promotes synthesis of starch made up entirely of branched molecules, while the starchy allel promotes synthesis of starch containing a mixture of straight and branched molecules.

SUMMARY

1. Starches were milled from corns having the following endosperm genotypes: Wx Wx Wx, Wx Wx wx, wx wx Wx, and wx wx wx, where Wx represents the gene for starchy and wx the gene for waxy endosperm.

2. As the ratio of waxy to starchy genes increased, the tendency toward waxy character in the starches also increased. The starchy genotype wx wx Wx corresponded in composition to a mixture of approximately 6 parts of non-waxy with 1 part of waxy starch.

3. Previous studies which established the complete dominance of the starchy gene used endosperm texture or iodine color to distinguish waxy from starchy corn. The use of more sensitive quantitative measurements as described in this paper, *viz.*, viscosity, gel strength, and potentiometric iodine titration, shows a definite waxy trend in starches from the genotype Wx Wx wx to that of wx wx Wx, both

of which by the older methods appeared identical with Wx Wx Wx starches.

4. The effect of the Wx allel appears to be additive in its action upon the viscosity and rigidity of the starch pastes and largely dominant with respect to its effect on the percentage of amylose present in the starch.

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FLAX VARIETIES REGISTERED, I[1]

A. C. Arny[2]

THESE are the first two flax varieties to be approved for registration. Biwing and Redson are selections from the cross Bison × Redwing made in 1929 at University Farm, St. Paul, Minn. The object in making the cross was to combine in new varieties the vigorous plant type, the moderately large seed size, the high oil percentage of the seed, and the high resistance to wilt, *Fusarium lini*, of the Bison parent with the high oil quality and the somewhat lower average rust infection, *Melampsora lini*, of the Redwing parent. Both parents had shown high yielding ability.

BIWING, REG. No. 1

The summarized data given in Table 1 for the rod-row tests covering the period 1936–42 show that Biwing averaged significantly higher in yield than Bison at St. Paul, Waseca, and Morris and equalled Bison in yield at Crookston. The average yield for all the tests is significantly higher for Biwing than for Bison. In the 1/40-acre plot tests, Biwing yielded at a significantly higher rate than Bison at Waseca. At St. Paul, Morris, and Crookston the yields

TABLE 1.—*Yields in bushels per acre of Biwing and Redson in comparison with those of Redwing and Bison.*

Variety	C. I. No.	St. Paul	Waseca	Morris	Crookston	Average
			Rod-row Tests, 1936–42			
Redwing....	320	15.7	18.8	16.5*	12.2†	15.8
Bison.......	389	10.7	15.9	12.9	13.4	13.0
Biwing......	917	14.2	18.5	16.9	13.2	15.6
Redson.....	970	14.2	18.4	16.9	13.3	15.6
Sig. dif......		1.65	1.84	1.45	1.61	0.82
			Fortieth Acre Plot Tests, 1941–42			
Redwing....	320	17.7	24.4	19.7	6.7‡	18.5
Bison.......	389	13.3	20.6	19.1	9.5	16.5
Biwing......	917	16.2	23.7	19.9	7.9	18.2
Redson.....	970	18.3	23.9	20.6	12.3	19.7
Sig. dif......		3.95	1.95	2.53	2.96	1.47

*No yield in 1939.
†No yields in 1939 and 1942.
‡Yield in 1942 only.

[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication May 12, 1943.

[2]Associate Agronomist, Division of Agronomy and Plant Genetics, Department of Agronomy, University of Minnesota, St. Paul, Minn. Member of committee on Varietal Standardization and Registration of the Society charged with the registration of flax varieties.

of Biwing and Bison were similar. The average yield for Biwing was significantly higher than that of Bison. In all of the tests, Biwing was similar to Redwing in yield.

The average data other than yield for all the tests given in Table 2 show that Biwing was similar to Redwing in height, wilt percentage, and rust infection, and approached Redwing closely in iodine number of its oil. In 1,000-seed weight, wilt percentage, and pasmo infection, *Phlyctaena linicola*, Biwing approached closely to Bison. In date of maturity, bushel weight, and oil percentage of the seed, Biwing was midway between its parents. Biwing has light blue flowers similar to those of Redwing.

TABLE 2.—*Additional comparative data for the four flax varieties, averages for all tests, 1938–42.*

Variety	Height, inches	Date mature	1,000 seed weight, grams	Bushel weight, pounds	Oil in seed, %	Iodine number of oil	Wilt av., 8 tests, %	Rust infection, av. 15 tests*	Pasmo infection, av. 9 tests*
Redwing...	25	July 31	4.4	54.5	35.7	183	23	M−	M
Bison......	26	Aug. 8	5.6	52.9	37.0	171	7	H−	L
Biwing....	25	Aug. 3	5.3	53.9	36.3	179	9	M−	L+
Redson....	25	July 31	5.4	54.5	36.2	181	3	M+	L+

*L = light; M = moderate; H = heavy.

REDSON, REG. No. 2

Redson averaged almost identical with Biwing in all yields in the rod-row tests at the four stations. Redson yielded significantly higher than its Bison parent in the tests at St. Paul, Waseca, and Morris and in the average for all locations. In the 1/40-acre plot tests in 1941–42, Redson yielded significantly higher than Bison in the tests at St. Paul, Waseca, and Crookston and in the average for all tests. In the 1942 test at Crookston, Redson yielded at a significantly higher rate than the other varieties. At the other three stations the yields of Redson were not significantly different from those of Redwing.

In the characters other than yield given in Table 2, Redson was similar to Redwing in height, maturity date, and bushel weight of the seed and approached closely to Redwing in iodine number of its oil. Redson approached closely to Bison in 1,000-seed weight, iodine number of its oil, and rust and pasmo infection and showed a somewhat lower percentage of wilt than Bison. In oil content of the seed Redson was intermediate between the two parents. Redson has dark blue flowers like those of Bison.

REGISTRATION OF VARIETIES AND STRAINS OF SWEET CLOVER, I[1]

E. A. HOLLOWELL[2]

COMMERCIAL seed of both biennial white sweet clover (*Melilotus alba*) and biennial yellow sweet clover (*Melilotus officinalis*) have become a mixture of different types and strains varying widely in degree of adaptation and desirability for different locations and uses. A considerable quantity of seed sold as sweet clover is a mixture of biennial white sweet clover and biennial yellow sweet clover. When such seed is shipped in interstate commerce in order to comply with the Federal Seed Act, the percentage of each species must be given, if more than 5% is present, or the seed must be labeled sweet clover without species designation.

A large part of the total sweet clover seed crop of the United States is produced in the region of western Minnesota and eastern North Dakota and South Dakota. Seed from this region produces semi-dwarf, early maturing types of biennial white and common biennial yellow sweet clover adapted to the culture and harvesting methods of that section. Their use in the seed-consuming sections of the Corn Belt states, however, reduces the potentialities of the crop, as the need there is for late-maturing, rank-growing strains to increase the quantity of forage and length of the grazing season.

The identification and multiplication of improved varieties and strains of sweet clover are desirable in order to preserve and make available seed containing the superior characteristics of this crop. Due to the problems of volunteer seed, pollination, and lack of seed-identifying characteristics, certification by state crop improvement associations seems essential to maintain the inherent superior qualities of the improved strains and varieties. Sweet clover varieties were registered in 1942 for the first time and three varieties have been approved for registration.

SPANISH, REG. No. 1

Spanish (P. I. 27, 465), a variety of *Melilotus alba* formerly called Madrid white, originated as an introduction through the Division of Plant Introduction and Exploration from the Madrid Botanical Garden, Madrid, Spain, in 1910. Early trials were limited and it was not until 1926 that it was widely distributed to state agricultural experiment stations.

Spanish, the progeny of bulked seed of the introduction, is biennial

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication May 12, 1943.

[2]Senior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering Agricultural Research Administration, U. S. Dept. of Agriculture. Member of the 1941–42 committee on Varietal Standardization and Registration charged with the registration of sweet clover varieties.

in growth habit and is white flowered. Leaf, stipule, stem, and flower characteristics are similar to common biennial white sweet clover. When compared with plants of other species and varieties of biennial white sweet clover, the characteristics of the first year's growth are as follows: Early seedlings vigorous, medium height, upright, foliage somewhat resistant to fall frost though not so resistant as the biennial yellow variety, Madrid. The second year's growth is leafy, upright, medium in height and in maturity. Seed production is heavy and early enough to escape the drought hazard common to the summer months in the eastern part of the Great Plains states. General regions of adaptation are the Corn Belt, Great Plains, and the intermountain states. The value of the variety has been clearly shown by comparative plantings in nurseries and field plots for the past 15 years. Yield data and discussions of the characteristics are presented in Table 1 and elsewhere (2, 3, 4, 8, 9).[3]

MADRID REG. No. 2

Madrid (P. I. 27, 474), a variety of *Melilotus officinalis* formerly called Madrid Yellow, originated as seed introduction through the Division of Plant Introduction and Exploration from the Madrid Botanical Garden, Madrid, Spain, in 1910. Similar to Spanish, it was not widely distributed to state agricultural experiment stations until 1926.

Madrid, the progeny of bulked seed of the introduction, is biennial in growth and yellow flowered. Leaf, stipule, stem, and flower characteristics are similar to those of common biennial yellow sweet clover. When compared with other varieties and strains of *Melilotus officinalis*, the first year's growth is characterized as follows: Exceptional early seedling vigor, medium height somewhat decumbent, foliage resistant to fall frost. The second year's growth is leafy, upright, of medium height, and slightly later in maturity. Seed production is heavy and of sufficient earliness to escape the hazard of drought common during the summer months in the Great Plains. Limited quantities of seed of Madrid sweet clover are available. Yield data and discussion of the characteristics of Madrid sweet clover are given in Table 1 and elsewhere (1, 2, 3, 4, 8, 9, 10).

EVERGREEN, REG. No. 3

Evergreen is a variety of *Melilotus alba* originated from plant selections made by J. B. Park, Department of Agronomy, Ohio Agricultural Experiment Station, Columbus, Ohio. Twenty-two individual plant selections were made in 1924 from fields and from mature roadside plants. One of these fields included a volunteer stand from an outstanding commercial late strain from the Park farm, first sown at the Ohio State University in 1921. One hundred and twenty-five additional selections were made in 1926 and 50 more in 1928 all of which were grown in plant-to-row progeny tests. Pollination was partially controlled by removing undesirable rows or plants.

[3]Figures in parenthesis refer to "Literature Cited", p. 829.

TABLE 1.—*Comparative hay yields in tons per acre of Spanish, Madrid, and common seed of biennial white and biennial yellow sweet clovers at various points.**

Variety	1931	1932	1933	1934	1937	1938	1939	Av.
			Manhattan, Kans.					
Spanish	3.23	2.15	1.84	1.19	3.39	1.62	3.78	2.46
Common biennial white	3.07	1.81	1.25	0.95	2.65	1.98	3.89	2.23
Madrid	2.96	2.69	1.83	1.04	1.98	1.47	2.55	2.07
Common biennial yellow	2.06	0.99	1.08	0.87	2.08	1.55	2.07	1.53
			Hays, Kans.					
Spanish	1.04	2.43	0.47	0.74	—	—	—	1.17
Common biennial white	0.98	2.27	0.29	0.67	—	—	—	1.05
Madrid	1.01	2.11	0.32	1.16	—	—	—	1.15
Common biennial yellow	0.64	2.19	0.39	0.53	—	—	—	0.94

Columbus, Ohio

	1934	1935	1936	1937	1938	1939	1941	1942	Av. %†
Spanish	—	—	—	—	2.54	—	2.99	2.38	105
Common biennial white	2.38	3.30	2.68	3.70	2.06	1.89	2.89	2.64	100
Madrid	—	—	—	—	2.46	—	3.46	3.06	118
Common biennial yellow	2.62	—	2.56	2.56	2.23	1.95	3.35	2.44	99

Ames, Iowa

	5-year av.
Spanish	3.40
Common biennial white	3.32
Madrid	2.95
Grundy County	2.61

Lincoln, Nebr.

	Pasture‡			Hay§		
	1941	1942	Av.	1941	1942	Av.
Spanish	1.58	1.73	1.66	2.01	2.50	2.26
Common biennial white	1.08	1.59	1.34	1.64	2.14	1.89
Madrid	1.41	1.61	1.51	1.61	2.45	2.03
Common biennial yellow	1.09	1.50	1.30	1.34	1.89	1.62

*Principally from unpublished data supplied by cooperating state Agricultural Experiment Station.
†Based on common white as 100%.
‡Cut three to four times to stimulate grazing.
§Each year's hay yield is the average of one first-year cutting and the total of two second-year cuttings.

Twenty strains were selected in 1928 and seven of these were sown in plots in the spring of 1929. From all available material, 11 mass selections of similar growth and maturity characteristics were made in 1930 and were increased as Ohio Nos. 1 to 11 in 1931 and 1933.

Considerable roguing was done in 1932. Some of these strains were distributed to farmers for trial in 1933. In the spring of 1935, seven of these mass selections were composited under the name "Evergreen".

Evergreen is white flowered, biennial in growth habit, and its leaf, stipule, stem, and flower characteristics are similar to common biennial white sweet clover. When compared to common biennial white sweet clover, the first year's growth is tall, upright and some-

TABLE 2.—*Comparative hay yields in tons per acre of Evergreen compared with common biennial white and common biennial yellow sweet clovers at various points.**

Variety	1937	1938	1939	1940	Av.
Columbus, Ohio					
Evergreen	5.62	2.64	3.64	—	3.96
Common biennial white	3.72	1.90	2.89	—	2.84
Common biennial yellow	2.57	2.33	3.35	—	2.77

Ames, Iowa

Evergreen	4.54 (4 years)
Common biennial white	3.32 (5 years)
Grundy County	2.61 (5 years)

Manhattan, Kans.

	1939		1940		1941		1942		Average	
	Hay, tons	Seed, bu.	Hay, tons	Seed, bu.	Hay, tons	Seed, bu.	Hay, tons	Seed, bu.	Hay, tons	Seed, bu.
Evergreen	5.24	5.26	4.62	2.61	3.86	1.62	3.91	5.61	4.41	3.78
Common biennial white	3.88	11.42	3.75	5.55	2.40	5.22	3.00	6.65	3.24	7.21
Common biennial yellow	2.07	10.50	2.71	6.61	2.13	3.31	3.62	6.40	2.63	6.71

Lincoln, Nebr.

	Average first and second year crops, tons					
	Pasture†			Hay‡		
	1941	1942	Av.	1941	1942	Av.
Evergreen	1.66	2.10	1.88	2.24	3.25	2.75
Common white	1.08	1.59	1.34	1.64	2.14	1.89
Common yellow	1.09	1.50	1.30	1.34	1.89	1.62

*Principally from unpublished data supplied by cooperating state agricultural experiment stations.

†Cut three to four times to simulate grazing.

‡Each year's hay yield is the average of one first-year cutting and the total of two second-year cuttings.

what coarser. The second year's growth is tall, coarse, and 3 to 4 weeks later in maturity than common biennial white sweet clover. In Ohio it blooms over a long period and sets seed freely. The harvesting of large seed yields is difficult because the seed shatters, due to the rank growth characteristics and the long blooming period. In the eastern edge of the Great Plains states frequent periods of high temperatures and drought are conducive to low seed yields or seed failures. Evergreen is well adapted throughout the Corn Belt and the eastern edge of the Great Plains states. Yield records and discussions of its characteristics are given in Table 2 and elsewhere (2, 4, 5, 6, 7, 8, 9).

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REGISTRATION OF VARIETIES AND STRAINS OF RED CLOVER, I[1]

E. A. HOLLOWELL[2]

IN 1928 the Bureau of Plant Industry of the U. S. Dept. of Agriculture, in cooperation with several state agricultural experiment stations, obtained approximately 75 lots of red clover seed, each of which had been grown on the same farm for a minimum of 10 years without any admixture of other seed. These were tested at three different places in the red clover belt. From these and other tests, three general regions (southern, central, and northern) of adaptation became evident, together with some of the factors that were important in each region (6).[3] While the old strains proved to be best adapted to the locality where produced, it was found that they could be moved latitudinally within limits of similar climatic factors without much loss in adaptation.

Concurrent experiments indicated that the red clover seed of the northwestern seed-producing states was not so satisfactory when used in the eastern seed-consuming states. Results of experiments also indicated that the growing of red clover varieties for successive generations in a location differing from the place of origin in factors affecting adaptation, reduced the productiveness of the variety when the progeny was planted in the original location.

Procedures and regulations pertaining to the maintenance of the superior characteristics of red clover varieties and strains have been developed and are given in the annual reports (7) of the International Crop Improvement Association. Certification of improved red clover varieties and strains is essential, since most of the varieties cannot be distinguished by seed or plant morphological characteristics. Red clover varieties and strains are being registered in 1942 for the first time and two varieties have been approved for registration.

CUMBERLAND, REG. No. 1

Cumberland, formerly called Southern Disease Resistant Blend, originated in 1937 as a composite of equal proportions of three identified superior strains, Kentucky No. 101 or No. 215, Tennessee Anthracnose Resistant, and Virginia (Sanford). This variety, the result of 13 years of breeding, testing, and increasing, was developed through a cooperative program of the Kentucky, Tennessee, Virginia, Idaho, Montana, Washington, Utah, Colorado, and Oregon

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication May 12, 1943.

[2]Senior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Member of the 1941–42 committee on Varietal Standardization and Registration charged with the registration of red clover varieties.

[3]Figures in parenthesis refer to "Literature Cited", p. 832.

agricultural experiment stations and crop or seed improvement associations, the International Crop Improvement Association, and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Provision is made for the substitution of other strains equal or superior to those used in the original composite in order to maintain an adequate stock of foundation seed necessary in the program. The objectives of the development of Cumberland are presented elsewhere (4, 7).

Cumberland has good growth characteristics, is resistant to southern anthracnose and crown rot, and is adapted to the southern region of the principal red clover belt. Yield data and discussion of the characteristics of Cumberland red clover are given in Table 1 and elsewhere (1, 2, 3, 4, 7, 8).

Approximately 120,000 pounds of certified Cumberland seed were produced in the states of Montana, Idaho, Washington, Utah, and Oregon in 1942 for use in the eastern states. Sources of Cumberland seed are available through state crop or seed improvement associations.

MIDLAND, REG. No. 2

Midland, formerly called Central Corn Belt Blend, originated as a composite of equal proportions of four old strains, Illinois (Rahn and Letcher), Ohio (Poland), Indiana (Otten), and Iowa (Emerson), in 1935. Due to drought conditions in 1930–36, the foundation seed stocks of the Indiana and Iowa strains were reduced to a few pounds and these have not been included in the composite for several years. These strains are being increased and as soon as sufficient seed is available they will be included in the composite. Provision is made for the substitution of other strains equal or superior to those used in the original composite in order to maintain an adequate stock of foundation seed necessary in the program. The more satisfactory Ohio (Kirch and VanFossen) strains have been substituted for the Ohio (Poland) strain. Midland, the result of 13 years of breeding, testing, and increasing, was developed through cooperative efforts of the Ohio, Indiana, Illinois, Iowa, Idaho, Washington, Utah, Oregon, Colorado, and Montana agricultural experiment stations and crop or seed improvement associations, the International Crop Improvement Association, and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture. The objectives of the development of Midland are presented elsewhere (5, 7). The procedures and regulations pertaining to the handling and increasing of Midland to preserve the superior characteristics are given in the annual reports (7) of the International Crop Improvement Association.

Midland has good growth characteristics, is winterhardy, and has some resistance to northern anthracnose. As the name suggests, it is adapted to the middle or central part of the Corn Belt states. Yield data and discussion of the characteristics of Midland red clover are given in Table 1 and elsewhere (1, 2, 5, 7, 8, 9).

TABLE 1.—*Comparative hay yields of Cumberland and Midland compared with other strains and common red clover at various points.**

Variety	1935	1936	1937	1938	1939	1940	1941	1942	Av. % based on Ohio as 100%
Lexington, Ky., yields on basis of Tennessee Anthracnose Resistant as 100%									
Cumberland.....	—	—	—	—	100.6	100.3	106.4	—	—
Midland...	—	—	—	88.3	65.9	99.7	96.7	—	—
Idaho.....	—	—	—	—	—	—	68.9	—	—
Virginia...	—	—	—	94.9	91.8	112.1	119.6	—	—
Kentucky .	—	—	—	106.3	101.6	114.6	115.7	—	—
Arlington Farm, Rosslyn, Va., Tons per Acre									
Kentucky†	2.83	—	3.62	2.27	—	—	—	—	—
Virginia† ..	2.52	—	3.18	1.95	—	—	—	—	—
Tennessee†	2.63	—	3.74	2.15	—	—	—	—	—
Idaho.....	—	—	2.73	—	—	—	—	—	—
Oregon....	1.50	—	—	—	—	—	—	—	—
Midland...	—	—	3.32	1.65	—	—	—	—	—
Urbana, Ill., Tons per Acre									
N. Ohio ...	—	—	—	3.88	2.08	—	1.22§	—	—
Midland...	—	—	—	3.91	2.64	—	—	—	—
Illinois....	—	—	—	—	—	3.17	—	—	—
Midland‡..	—	—	—	—	—	3.58	1.36§	—	—
Ames, Iowa, Tons per Acre									
Midland...	—	—	—	3.29	2.32	3.24	2.50**	—	—
Oregon....	—	—	—	—	—	3.00	1.93**	—	—
Idaho.....	—	—	—	—	—	3.15	—	—	—
Iowa......	—	—	—	3.18‖	2.25	—	2.99††	—	—
Columbus, Ohio, Tons per acre									
Ohio......	—	1.72	3.94	4.04	1.77	—	2.40	—	100
Midland...	—	2.10	3.59	4.12	1.88	—	2.30	—	104‖
Cumberland.....	—	—	—	—	2.20	—	2.14	—	106

*Principally from unpublished data supplied by cooperating state agricultural experiment stations.
†Cumberland is composed of these strains.
‡Average of three lots.
§One cutting the second year.
‖Average of two strains.
**Average of two lots.
††Emerson strain.

Approximately 220,000 pounds of certified Midland seed are available for planting in the eastern states in 1943. Sources of seed may be obtained through state crop or seed improvement associations.

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SOYBEAN VARIETY REGISTERED, I[1]

W. J. MORSE[2]

THE first variety of soybean for registration under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy was submitted by Dr. W. C. Etheridge of the Missouri Agricultural Experiment Station.

BOONE, REG. No. 1

Boone is a pure line selection from P. I. 54563-3[3] made by the Missouri Agricultural Experiment Station at Columbia, Mo., in 1930. P. I. 54563-3 originated from a selection made by W. J. Morse in 1922 from P. I. 54563, received from Jungchiangko, Manchuria, in 1921. The selected strain, now named Boone, first distributed in 1935, is commercially grown on a moderate scale in central and southern

TABLE 1.—*Annual and average acre yields in field plots of Boone and two standard varieties at Columbia, Mo., 1937–41, inclusive.*

Variety	Yields in bushels per acre					
	1937	1938	1939	1940	1941	Average
Boone	16.2	20.2	19.1	21.4	25.1	20.4
Manchu	12.0	19.7	18.0	22.7	19.8	18.4
Illini	11.0	20.9	14.0	15.9	17.2	15.8

TABLE 2.—*Three-, four-, and five-year average yields of Boone and four standard varieties for three Missouri stations.*

Variety	Location and bushels of seed per acre		
	Columbia, 4-yr. average	Elsberry, 3-yr. average	Sikeston, 5-yr. average
Boone	21.0	24.8	23.8
Scioto	21.6	22.1	—
Illini	16.5	21.1	18.7
Dunfield	17.5	18.3	14.4
Manchu	19.5	20.1	18.1

[1]Registered under cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication May 12, 1943.

[2]Senior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and member of the 1942–43 committee on Varietal Standardization and Registration charged with the registration of soybean varieties.

[3]P. I. refers to plant introduction number given by the Division of Plant Exploration and Introduction.

Missouri. It is grown under different names in various localities, most often as "Missouri Selection." It is generally well liked by farmers, particularly for upland soils of moderate fertility in central and southwestern Missouri. The most common objection to Boone is that its late maturity brings its harvest too late in the fall to be followed by timely seeding of wheat.

The variety has been thoroughly tested at eight different locations in the state, either on state experiment fields or in cooperation with farmers. The results obtained on experiment fields are given in Tables 1 and 2.

The following descriptive notes on the variety were submitted by Dr. W. C. Etheridge in the application for registration of Boone: Plants medium tall, determinate in growth habit; branches short; stalks medium coarse, standing well for harvest except on very rich land; pubescence gray; flowers white; pods mostly 2-seeded, resistant to shattering; seeds medium to small, straw yellow with light brown to pale hilum; oil, 19.91%; protein, 42.18%; maturity 125 to 130 days, or about the same as the Virginia variety.

NOTE

A TECHNIC FOR GROWING SEEDLINGS OF GRASS AND OTHER PLANTS FOR FIELD TRANSPLANTING

WHEN the seed supply for a field planting is limited, or when plantings of single, spaced plants are desired, a common practice has been to start the seedlings under favorable conditions in the greenhouse or hotbed and transplant them to the field. Such a procedure is particularly effective in the establishment of experimental plantings of many forage grasses when individual plants are to be studied. Low germination in some species and lack of seedling vigor in others result in considerable difficulty in securing uniform stands when single seeds are planted directly in the field.

None of the usual technics in seedling culture seem particularly suitable for handling large numbers of grass seedlings. Grass plants, for transplanting, cannot ordinarily be started in flats without partitions of some kind to keep the individual plants separated. The smallest available clay or fiber pots and wood veneer or paper bands were not considered practical for grass seedlings when thousands of plants must be grown each spring in limited greenhouse space and at a reasonable cost. A plant band method for handling seedlings of grass and other forage crops prior to their transfer to the field has been developed which may be of value to others engaged in crop improvement programs.

Tests were run with several kinds of paper made into bands of various sizes to determine the most suitable container for growing grass seedlings in the greenhouse for periods of 2 to 8 weeks. The aim was to develop a plant band (1) of the minimum dimensions necessary to produce a seedling of sufficient size to permit successful establishment under field conditions, (2) which need not be removed from the roots at the time of transplanting, (3) made from inexpensive and accessable material, and (4) which would keep the root systems of individual plants separate during the greenhouse growing period.

Types of paper tested included No. 10 asphalt building paper; plain, oiled, and paraffined, 50-pound kraft wrapping paper; and plain and paraffined newsprint paper. Plant bands 3¼ inches deep and ¾, 1, and 1½ inches square were made from these materials. The completed bands were set up in redwood flats and filled with a soil fertilized with either ammonium sulfate or a 4–12–4 commercial fertilizer. Investigations carried out by Youden and Zimmerman[1] and others have shown that in order to produce normal growth nitrogen must be added to the soil when seedlings are grown in fiber or paper containers.

Greenhouse and field trials showed that bands ¾ × ¾ × 3¼ inches made of untreated newsprint most nearly satisfied the requirements for grass seedlings. When filled with sandy loam soil to which commercial fertilizer had been added, these containers provided satisfactory conditions for growth of grass seedlings for at least 8

[1]YOUDEN, W. J., and ZIMMERMAN, P. W. Field trials with fiber pots. Contr. Boyce Thompson Inst., 8:317–331. 1936.

weeks under greenhouse conditions. Seedlings grown in the smaller bands were fully as large as those produced in the larger sizes. Furthermore, in an equal space, four times as many seedlings could be grown in ¾-inch as in 1½-inch bands. Matting of roots on the bottoms of the flats occurred regardless of the size or kind of plant band. The root systems of the individual plants in the ¾-inch bands were, however, readily separated for transplanting. The photographs in Fig. 1 show grass seedlings 8 weeks old grown in ¾-inch newsprint bands.

In a dry-land planting made during the spring of 1941, in which 9,000 seedlings of a wide variety of grass species were set out, a survival of 94% was recorded in mid-summer. These seedlings had been started in the greenhouse in ¾-inch bands and were only 16 days old when transplanted. As good, and probably better, establishment could be expected from larger seedlings under the same conditions. The net cost per 100 plants was 37 cents for all processes involved in establishing the seedlings in the field, including setting up the bands, filling the flats with soil, planting the sprouted seeds in the bands, and transplanting to the field. This cost was figured on the basis of labor at 35 cents per hour. An added benefit, not shown in the cost, was the small amount of greenhouse space used for starting the seedlings. The 9,000 seedlings growing in newsprint bands in flats required a space of only 4 × 12 feet.

This seedling technic has also been used successfully with alfalfa and clovers. The method may be useful for any plants with which crowding would not occur while growing in the bands, or, when this factor would not be a limiting one in subsequent growth or survival of the seedlings in the field.

SEEDLING TECHNIC

Sheets of common newsprint paper, 3½ × 3¼ inches, are obtained from a printing shop for a few cents per thousand. The bands are shaped by folding with pressure around a sharp-edged block of hardwood having dimensions of ¾ × ¾ × 5 inches (Fig. 2A), and placed between supports B and C (Fig. 2) while still wrapped around the block. The block is then removed and the band retains the desired shape. The sheets of newsprint are folded with the longer axis (3½ inches) at right angles to the block. When folded in this manner, there is an overlap of ½ inch on the side of the band placed against support C. Vertical lines ruled on support B at ¾ inch intervals aid in proper spacing of the bands. As each row of bands is completed, support B is removed and inserted between the last row and support C. Support C is then removed and placed in the next slot forward in the cross-supports, D. While the first few rows of bands are being folded, the support E, placed near the center, holds the slotted cross-supports in position between the second and third bands from either end of the flat. The support E may be removed when enough rows of bands have been set up to hold the cross-supports in position. The supports D are removed when the flat is filled with bands. When completely filled, a flat having inside dimensions of 15 × 22½ inches (Fig. 2), contains 600, ¾-inch bands.

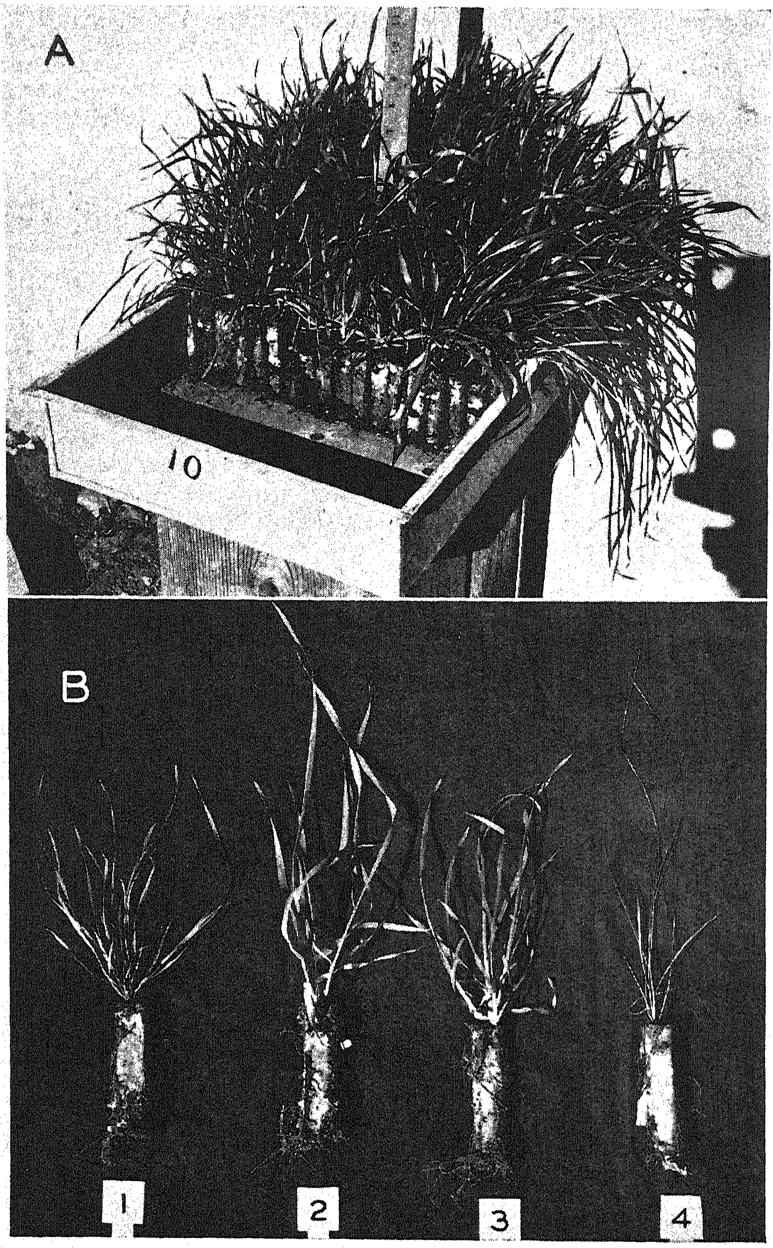

FIG. 1.—Appearance of grass seedlings grown for 8 weeks in ¾-inch newsprint bands. Individual seedlings in B were taken from the flat in A and are (1) *A. trachycaulum*, (2) *B. inermis*, (3) *D. glomerata*, and (4) *F. rubra*.

A redwood flat is shown in Fig. 2 partially filled with ¾-inch newsprint bands to illustrate the procedure of folding and placing the bands in position. By modifying the length dimensions of the supports, other shapes and sizes of flats may be used with these bands in a manner similar to that described. Little experience is required to set the bands up after the necessary supports have been made.

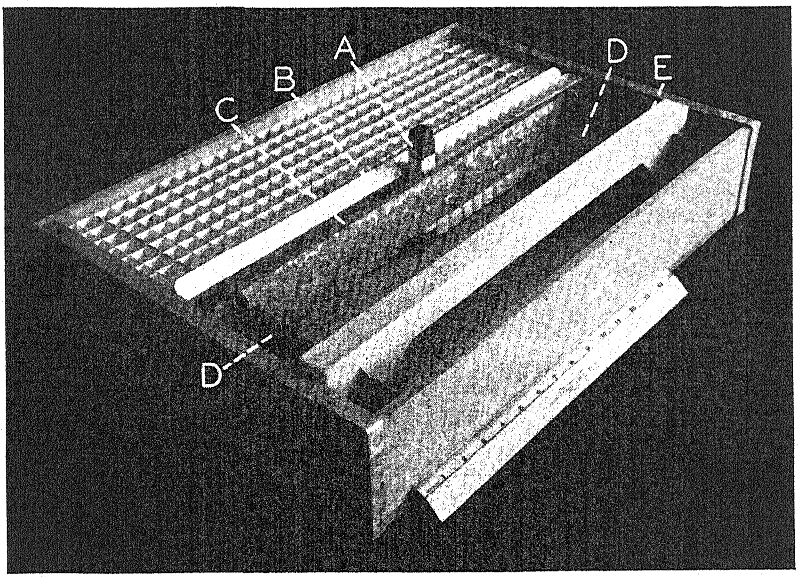

FIG. 2.—Greenhouse flat, 15×22½×3¾ inches inside, partially filled with ¾-inch newsprint bands. A, block, ¾×¾×5 inches, with sharp metal edges; B and C, supports, 3×22¼ inches, 28 gage galvanized iron with the upper ¾ inch bent at a 45° angle; D, cross supports, 3⅜×14¾ inches, 24 gage galvanized iron, and containing 19 slots, $\frac{1}{16}$×2⅜ inches, spaced at ¾-inch intervals; E, support, 1⅛×2¾×22¼ inches, with a vertical saw cut 2 inches deep 1½ inches from either end; F, removable side.

Soil used in filling the newsprint bands must be dry and contain at least supplemental nitrogen. The most successful practice has been to mix 100 grams of a powdered, complete commercial fertilizer (Vigoro) having a 4–12–4 composition to each 5 gallons of screened soil before filling the bands. Failure to provide more nitrogen than is present in even a fertile soil results in a stunting of seedlings in a very short time. The bands are filled to the top and the excess soil scraped off. By tapping the bottom of the flat the soil will settle to about ¼ inch below the top of the bands. The soil in the bands is saturated with water immediately before seeds are planted.

Seedlings are started in the flats by placing a germinated seed in each band. Shallow trays or pot saucers filled with soil and saturated with water provide satisfactory containers for germinating the seeds. The seeds are placed on the surface of the soil and the saucers or

trays placed in a closed chamber until sprouts appear.[2] The germinated seeds are transferred with forceps to the water-saturated soil in the bands before the sprouts have reached a length of 1/4 inch and covered with soil to a depth of 1/8 to 1/4 inch. This planting procedure has usually resulted in a better than 95% stand of seedlings in the bands. Planting of sprouted seeds in the bands is more rapid than pricking off seedlings in the usual manner and, in addition, decreases the chance for the entrance of damping-off organisms into the seedlings via injured rootlets.

For transplanting, easy access to the plants is provided by removing one side of the flat (Fig. 2F). Transplanting is accomplished by dropping the column of soil and roots held intact by the band into a hole made by a dibble[3] of a slightly larger diameter than the band. Soil is firmed around the band and roots by applying pressure to one side of the hole with the heel of the foot placed 2 or 3 inches from the hole. A crew of four men has transplanted over 4,500 grass seedlings grown in 3/4-inch newsprint bands in 8 hours following this procedure.—DEAN F. MCALISTER, *Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Logan, Utah.*

[2]Another convenient method of sprouting seeds has been to place seeds on the botton of an inverted, clay pot saucer which has previously been soaked in water. When covered with another saucer or placed in a moist atmosphere, the water supplied by the saucer is often sufficient to produce germination. Water may be added to the seeds from time to time with an atomizer or any device which will produce a fine spray.

[3]A very convenient dibble, which is operated from a standing position, consists of a 1 1/4-inch, round, iron pipe 5 1/2 feet long with a closed, bluntly pointed lower end. A 5-inch collar welded in a position 3 1/2 inches from the shoulder of the point regulates the depth of the hole. This tool was designed by Dr. John W. Carlson, Associate Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Logan, Utah.

BOOK REVIEWS

THE NATURE AND PROPERTIES OF SOILS

By T. Lyttleton Lyon and Harry O. Buckman. New York: The Macmillan Co. Ed. 4. XI+499 pages, illus. 1943. $3.50.

THIS volume is the fourth edition of this well-known college text book. The revision made by Harry O. Buckman is thorough and complete. More emphasis of a technical nature is placed on the physics of soil moisture and the chemistry of the colloidal state than in preceding editions, but important subject matter has not been deleted. Soil conservation is considered in the broad sense and is discussed as an integral part of several topics as soil moisture, soil colloids, soil organic matter, fertilizers, and soil management.

The volume has excellent references to subject matter and contains a complete author and subject index. It is a valuable, timely, and up-to-date contribution. (R. I. T.)

THE DIAGNOSIS OF MINERAL DEFICIENCIES IN PLANTS BY VISUAL SYMPTOMS: A COLOR ATLAS AND GUIDE

By T. Wallace. London: H. M. Stationary Office. VI+116 pages, illus. in color. 1943. 10/–net.

THIS publication by Doctor Wallace, the well-known worker at the University of Bristol Agricultural and Horticultural Research Station at Long Ashton, Bristol, is a contribution of the Agricultural Research Council of Great Britain.

The war has apparently created many new problems in British agriculture with its speeding-up program and the placing of a large acreage of grassland under the plow. This program has revealed many new mineral deficiencies in crops. Obviously, such deficiencies must first be recognized and diagnosed, so that this feature, based on changes produced in a selected series of indicator plants, is a main feature of the volume.

The 52 pages of text are aimed at laying a background and are concerned with the essential points in plant nutrition, relation of soils to mineral supply, methods of determining deficiencies, visual symptoms, a guide to symptoms in farm, garden, and fruit crops, and the use of the visual method in field diagnosis. The text also contains a considerable bibliography.

The remainder of the volume is taken up by 114 color photographs. Although the color reproduction in many cases is not all that might be desired, it is generally sufficiently good for the purpose intended. A valuable feature is the fact that some attempt at least is made to illustrate not only deficiency symptoms, but also results of excess concentration, normal senility changes in foliage, and insect and disease damage. It is unfortunate that these latter causes, which are many times so confusing in diagnosis, could not have been more fully presented. This, however, is a criticism which can be made of all the publications on this subject.

The volume is a valuable addition to "Hunger Signs in Crops" recently published by the National Fertilizer Association in this country.—(R. C. C.)

MIRROR FOR AMERICANS: LIKENESS OF THE EASTERN SEABOARD, 1810

By Ralph H. Brown. New York: American Geographical Society. Special Publication No. 27, XXXII+312 pages, illus. 1943. $4.00.

ALTHOUGH primarily a geography, this is both a most informative and delightful book for the agronomist. It is more than a descriptive text of the physical geography of the eastern seaboard in 1810, or a careful compilation of the occupations of the people of that day based upon exhaustive research of authentic documents; it is indeed a mirrored reflection from the past showing a living generation going about its daily tasks. We catch glimpses of life on the plantations in the South, on the fringe of settlement in the Genesee Country, on the docks of Boston, on the fishing vessels headed for the Grand Banks, in the new cotton mills of Rhode Island, and on the post roads that extend westward.

Of special appeal to the agronomist are those parts of the books which give a picture of the agriculture of the period. Regional differences are clearly set forth; landscapes and local patterns of land use are brought out. The adaptations and distribution of the principal crops—corn, tobacco, wheat, cotton, rice, and indigo—are described together with accounts of cropping practices and farm management methods. This entire descriptive record of regional agriculture is based upon the papers and journals of eye-witnesses and excerpts have been effectively used and placed in the text to bring out detailed observations. Reference is also made to topics of debate, such as whether or not the climate is changing, and the role of such plants as clover, peas, and beans in the fertilization of worn-out soils.

The author states that the volume is intended as a short-cut to an understanding of American geography in 1810. The opening paragraph of the Preface, taken from Robert Rogers, famous leader of the Rangers, exemplifies the spirit of the book, although written under a different political situation. The quotation is as follows:

"It will not be expected, after volumes upon volumes that have been published concerning the Bri(t)ish colonies on the eastern shore of the American continent, that any thing materially new can be related of them. The only thing I mean to attempt with regard to this is, to collect such facts and circumstances, as, in a political and commercial view, appear to me to be most interesting; to reduce them to an easy and familiar method, and contract them within such narrow limits, that the whole may be seen as it were at once, and every thing material be collected from a few pages, concerning seventeen Provinces; a minute and circumstantial account of which would fill so many considerable volumes." (1765)

The author has displayed unusual talent in writing the text in the style of the period, and in hiding his identity behind that of Thomas

Pownall Keystone—a geographer created by Professor Brown. Following the preface and introduction, Professor Brown introduces in the prologue the character of geographer Keystone, his library, and his contemplated work, "Mirror for Americans."

"Mirror for Americans", proper, contains 14 chapters entitled, Natural Traits, A View of the Population, Ways of Travel, The Principal Occupations, The Maritime Interests, Seaboard Commerce, Northern Border Regions, Southern Border Regions, The Inlands of New York, Southern New England, Eastern Pennsylvania, The Chesapeake Country, The Carolina Low Country, and Selections from the Library of T. P. Keystone. In the words of Keystone, the text is "Embellished with illustrations and maps." In addition, Professor Brown has supplied an index and 39 pages of notes containing references to source material. All in all, Professor Brown is to be highly complimented for this excellent volume. (J. K. A.)

AGRONOMIC AFFAIRS

MEETINGS TO BE HELD AS SCHEDULED

AFTER careful consideration, the Executive Committee has definitely decided to hold the annual meeting of the American Society of Agronomy and Soil Science Society of America in Cincinnati November 10 to 12, inclusive, as originally scheduled. The Netherland-Plaza Hotel has been selected as headquarters. It is the feeling of your Executive Committee that these meetings are definitely linked with the war effort and that, in spite of transportation difficulties, we can best serve our nation by continuing with our original plans. A strong program has been built up to help point out ways in which agronomists may help in the war effort.

The general program of the Society will be addressed by Dr. L. A. Maynard of the School of Nutrition, Cornell University, who will talk on "The Soil and Crop Bases of Better Nutrition," and by Dr. O. E. May, Agricultural Research Administration of the U. S. Dept. of Agriculture, who will speak on "The Contribution of the Processing Laboratories to the War Effort Program."

The Soil Science Society general program will be a symposium on "The Efficient Use of Fertilizers During the War in Relation to the Major Soil Groups." In addition, the Soil Science Society will hold an evening meeting commemorating the 100th anniversary of the founding of the Rothamsted Experimental Station. Sectional programs will also deal with various problems relating to the war effort.

The Crops Section will have two general programs, one on "Agronomic Contributions and Their Current Significance", and the second on "Physiological Aspects of Agronomic Research." Sectional programs with special emphasis on war production include sessions on hemp, sugar beets, pastures, and crop breeding.

It is expected that the attendance may be smaller than in recent years but it is hoped that each state may be well represented and that these men will carry the message back to the other agronomists in their states.—G. G. POHLMAN, *Secretary*.

DOCTOR BALL RETIRES

DOCTOR Carleton R. Ball, Principal Agriculturist and Executive Secretary of the Correlating Committee of the U. S. Dept. of Agriculture, the Tennessee Valley Authority, and the Valley-States Land-Grant Colleges since 1935, retired from the federal service on June 30, after 47 years in state (Iowa, California) and federal work. Entering the U. S. Dept. of Agriculture in 1899, he was Chief of the Division of Cereal Crops and Diseases from 1918 to 1930, in which period all its field work was brought into cooperation with the state experiment stations. During 1931–35, while with the Bureau of Public Administration, University of California, he authored two volumes covering the history and status of all government (federal, state, and county) cooperation in agricultural activities. Now, as a collaborator of the Department, he is located with the Extension Service, and is working on uncompleted projects, including a companion volume on cooperation in natural resources, a monograph of the willows, a history of American agriculture, and a little book on how to write technical manuscripts.

(N.B. Doctor Ball is a charter member of the Society and has served it in many capacities, including the presidency and the chairmanship of important committees. He was the first secretary and by virtue of that office edited the first four volumes of "Proceedings" to be published by the Society. He also inaugurated the publication of the present Journal in 1913 and served as editor of the JOURNAL through 1914. For this and other reasons, he is eminently qualified to write on the subject of the preparation of technical manuscripts.)

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STAGE OF CUTTING STUDIES: I. GRASSES[1]

J. N. BIRD[2]

THE habit and rate of growth, season of maximum production, and duration of the period over which active growth occurs are all important factors in determining the adaptation of a species or strain of grass to management practice. Because they are different in these respects, species and strains react differently to cutting and grazing practices and this determines, to a large extent, the yield, feeding value, and longevity of their stands.

In Canada we have four grass species which are well adapted to the climatic and soil conditions prevailing throughout large areas of the more humid sections of the country. These are brome grass, *Bromus inermis* Leyss, timothy, *Phleum pratense* L., red top, *Agrostis alba* L., and Kentucky bluegrass, *Poa pratensis* L. They are the most productive and the most commonly used grass species in seed mixtures, and it is mainly for these reasons that they have been selected for comparison in this study.

Although stage of cutting studies have been carried out elsewhere with individual species of the group or of one species in comparison with one or two of the others, it was considered advisable to conduct a stage-of-cutting study which would include the entire group.

STAGE OF CUTTING

The stage of growth which a plant has reached at the time of cutting is one of the most important considerations in connection with the harvesting of forage crops. Both the increased production of stem and resulting changes in the proportion of stem to leaf as a plant matures have a marked influence upon the yield and feeding value of the crop obtained. The rapid increase of stem during the period immediately preceding bloom and the withering and loss of

[1]Contribution from the Faculty of Agriculture of McGill University, Macdonald College, P. Q., Canada. Journal Series No. 160. Received for publication April 20, 1943.

[2]Lecturer in Agronomy. The author is indebted to Professor R. Summerby, Head of the Department of Agronomy, for assistance and advice in connection with this study, and to Mr. W. A. Brechin of the Chemistry Department for nitrogen and carotene determinations on samples.

lower leaves in the advanced stages of maturity account for marked changes not only in yield but also in the chemical composition, palatability, and digestibility of a grass plant in the later stages of growth.

Leaf tissue is known to be richer in protein, calcium, and carotene and lower in fibre than stem tissue. The significance of leaf and stem in determining the chemical composition and feeding value of grasses has been pointed out by Fagan and Jones (3)[3] and, more recently, by Hosterman and Hall (6). Many studies on the chemical composition and feeding value of grasses have been reviewed by Arny (1), Graves, *et al.* (4), and Huffman (7).

In general, all such studies have shown that as a grass plant approaches maturity, the percentage of protein decreases while the percentage of crude fibre increases; that, with the slackening off in growth during the advanced stages of maturity, there is a pronounced decline in the palatability and digestibility of the herbage; and that an increase in yield of dry matter in the advanced stages of maturity is obtained only at a sacrifice of feeding value.

Where perennial hay and pasture grasses are concerned, no study can be regarded as complete which does not take into account the yield of later cuttings, especially those produced in the same year. The stage of growth at which the first cutting is made determines the period over which aftermath growth may take place and, together with seasonal and soil conditions, the extent of this growth. Furthermore, the cutting treatment used in any year may influence the yield obtained in the following year.

MATERIALS AND METHOD

According to the original plan, seedings of the four species of grasses were to be made each year in late July, without a nurse crop, and yields were to be taken in the second year following seeding. This was to allow for a thorough establishment of stands of all species. After following this plan for a 3-year period, it was revised in favor of yields taken in the first year after seeding, as it seemed possible to get well-established stands of all species by this time. The revised plan was followed for the three remaining years of the study.

Although it was originally planned to obtain yields in only one year from each test, opportunity was taken on two occasions to measure a possible after-effect of the cutting treatments used. This was done by taking a hay cutting at the late-bloom stage from all plots of each species which had been subjected to selected cutting treatments in the previous year (Table 3).

In selecting the stages of growth at which the cutting treatments would be made, the necessity of having easily identified stages was kept in mind. In the first three of the six tests involved in this study (series I), the cuttings were made at what might be called "hay" stages, *viz.*, beginning of heading, beginning of bloom, end of bloom, and when seed had formed. As no aftermath cuts were taken from this series, the yields reported are for the first (hay) cutting only. In the last three tests (series II) two earlier "grass" stages were introduced. The first of these, short grass, permitted five to six cuttings to be made per season while the second, long grass, permitted two to four cuttings, depending

[3]Figures in parenthesis refer to "Literature Cited", p. 860.

on the species and the seasonal growth conditions. In series II both a hay and an aftermath cutting were taken from the remaining four "hay" stages already mentioned.

The cuttings at the short grass stage were made on the same date for all species. They were made with a rotary-bar mower set fairly close to the ground in order to simulate, as far as possible, a close-grazing treatment. The cuttings at all other stages were made on dates which varied considerably with each species and for these a sickle-bar mower was used. The nature of the growth of the four species at the different cuttings from the six stages is illustrated in Figs. 1 to 4.

The plot arrangement followed essentially the same plan throughout the study. There were four, large species plots randomized within each of four blocks in a 2×2 arrangement so that the blocks were almost square. Within each of these large species plots, sub-plots for the various stages of cutting treatments were randomized.

Yields were calculated in tons of dry matter per acre and the data statistically analysed by the variance method. Only the summaries are presented in this paper. The principal details relative to the experimental procedure are summarized in Table 1.

TABLE 1.—*Details relative to experimental procedure.*

Series No.	Seeding year	Harvest year	Number of species	Number of replicates	Size of plot*	Number of stages
I	1933	1935	3	4	7×40 links	4
I	1934	1936	4	4	7×40 links	4
I	1935	1937	4	4	7×40 links	4
II	1936	1937	4	2	6×40 links	6
II	1938	1939	4	4	6×40 links	6
II	1939	1940	4	4	5×40 links	6

*Net size of plot harvested after removal of borders.

RESULTS

SEASONAL DEVELOPMENT

The four species of grasses used in this study varied considerably in the time of year at which they reached corresponding stages of growth. The average dates at which they reached the various stages are shown in Table 2. The actual dates, of course, varied somewhat from year to year with different seasonal conditions. At certain stages the grasses proved more sensitive to seasonal conditions

TABLE 2.—*Average date at first cutting, series I and II.*

Stage of cutting	Brome grass	Timothy	Red top	Kentucky bluegrass
1, short grass.	May 21	May 21	May 21	May 21
2, long grass.	May 29	May 29	June 13	May 29
3, begin to head.	June 5	June 14	June 23	May 29
4, begin to bloom.	June 23	June 28	July 4	June 11
5, end of bloom.	June 29	July 6	July 12	June 19
6, seed formed.	July 6	July 19	July 19	June 25

than at others. For example, at stage 4, the beginning of bloom was delayed by cool showery weather and hastened by dry sunny weather. Brome grass proved especially sensitive at this stage and its irregular behavior made the identification of its beginning-of-bloom stage rather difficult. The development of Kentucky blue-

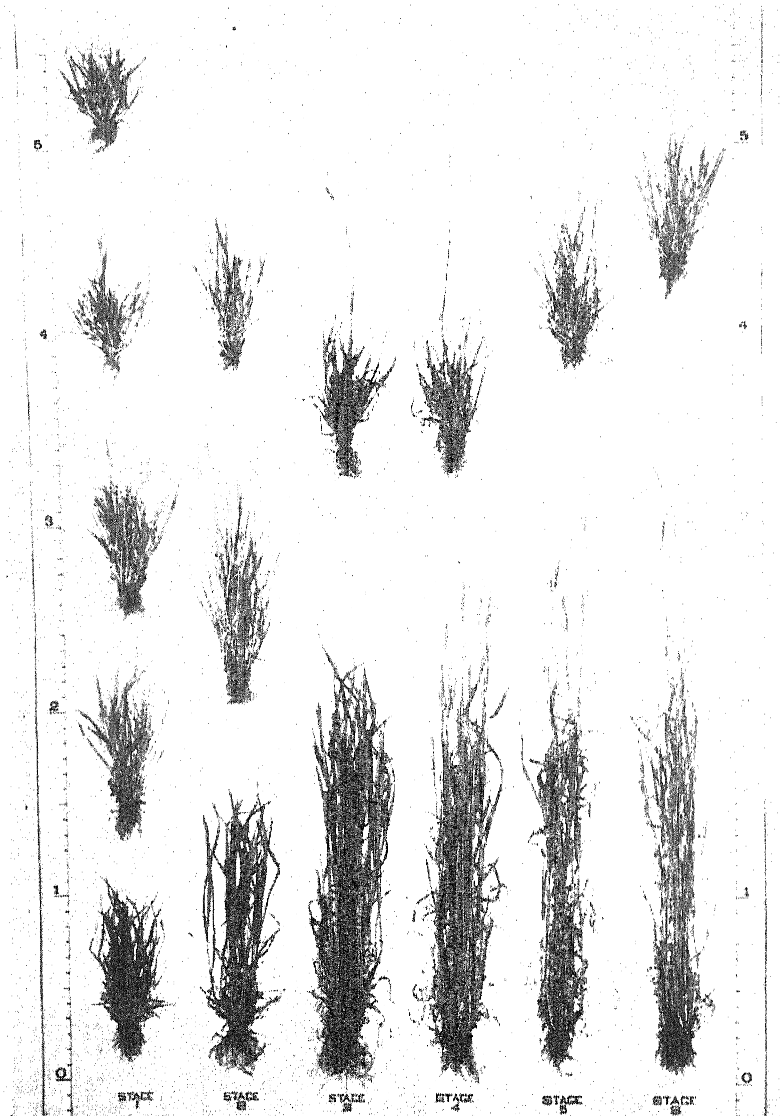

FIG. 1.—Samples of timothy from cuttings made at different stages of growth.

grass during late May and early June was so rapid that it was impossible to make any clear distinction between stages 2 and 3 with this species, hence the data for the two stages are essentially the same.

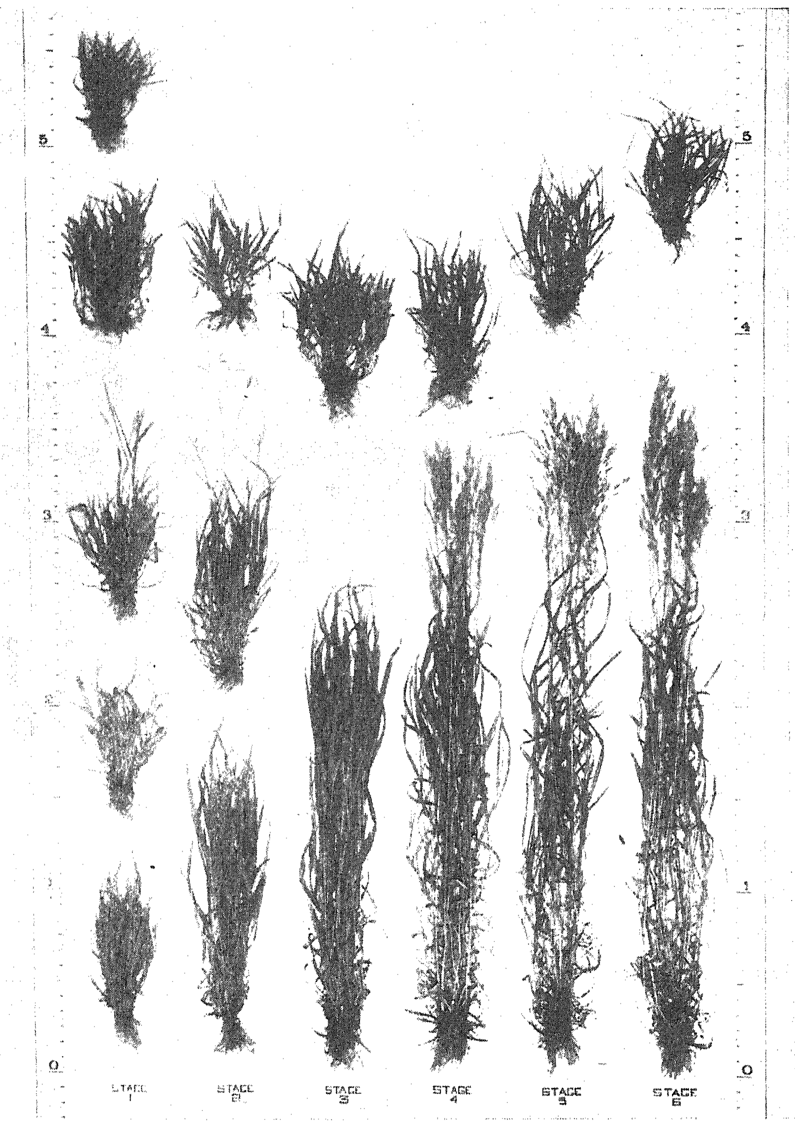

FIG. 2.—Samples of brome grass from cuttings made at different stages of growth.

YIELDS AT FIRST CUTTING, "HAY" STAGES

Yields obtained at the first cutting of the four "hay" stages are presented in the first section of Table 3. The analysis of variance for the data in Table 3 is given in Table 4. Data for the years 1935, 1936, and 1937 from series I and for the years 1939 and 1940 from

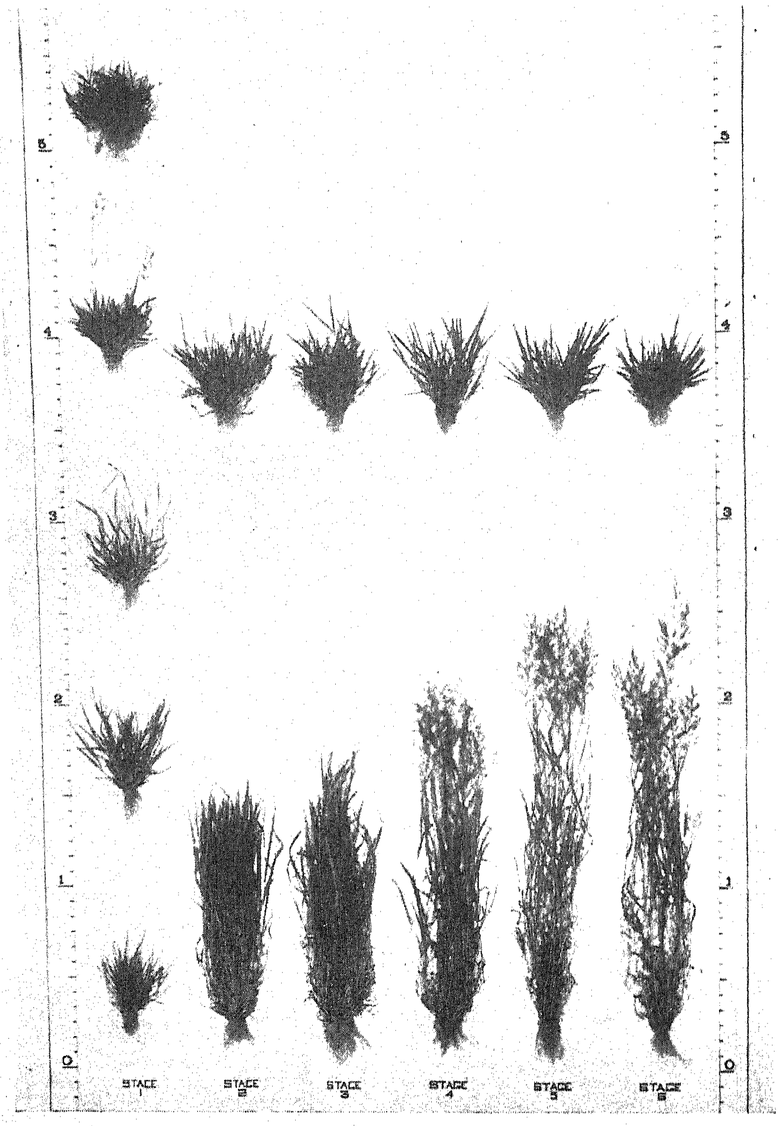

FIG. 3.—Samples of red top from cuttings made at different stages of growth.

series II have been combined to provide a 5-year average. Data for the year 1937 from series II have not been used in this comparison as they were based upon two replications only, whereas all other data were based upon four replications. It should also be pointed out that the yields obtained in series I were somewhat

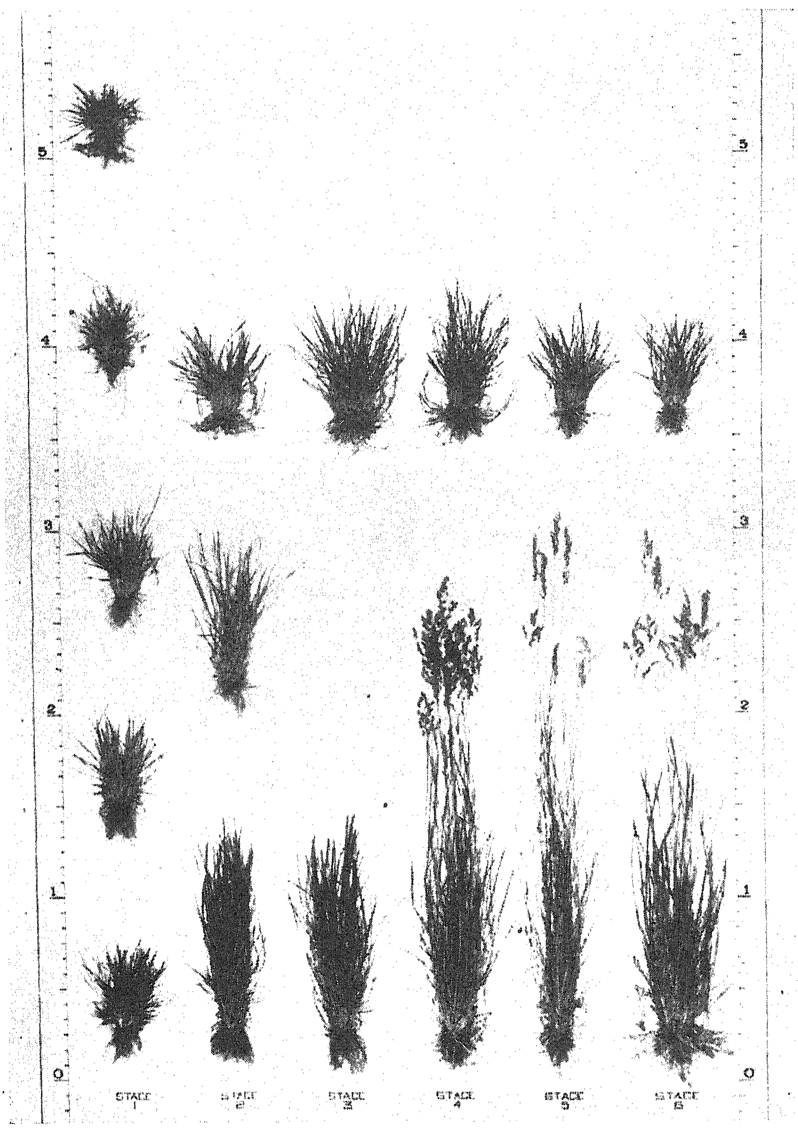

Fig. 4.—Samples of Kentucky bluegrass from cuttings made at different stages of growth.

TABLE 3.—*Yields of grasses cut at different stages of growth.*

Stage of cutting	Yields at first cutting, "hay" stages, 5-year mean, dry yield in tons per acre, series I and II combined, 1935, 1936, 1937, 1939, 1940					Yields from all cuttings, all stages, 3-year mean, dry yield in tons per acre, series II, 1937, 1939, 1940					After effect of cutting treatments, 2-year mean, dry yield of hay in tons per acre, series II, 1940 and 1941				
	Brome grass	Timothy	Red top	Kentucky bluegrass*	Means for stages (3 species)	Brome grass	Timothy	Red top	Kentucky bluegrass	Means for stages (4 species)	Brome grass	Timothy	Red top	Kentucky bluegrass	Means for stages (4 species)
1, short grass	—	—	—	—	—	1.34	1.37	1.24	1.18	1.28	1.06	1.04	0.97	0.85	0.98
2, long grass	—	—	—	—	—	1.79	1.87	2.19	1.47	1.83	1.03	1.04	1.09	0.79	0.99
3, begin to head	1.28	1.35	1.35	0.65	1.33	2.46	2.64	2.38	1.79	2.32	1.32	1.21	1.13	0.83	1.12
4, begin to bloom	2.14	1.74	1.54	1.03	1.81	3.31	2.88	2.72	2.00	2.73	1.57	1.28	1.19	0.87	1.23
5, end of bloom	2.25	1.79	1.65	1.17	1.90	3.22	2.95	2.55	2.26	2.75	1.28	1.34	1.04	0.92	1.15
6, seed formed	2.37	1.95	1.54	1.28	1.95	3.39	2.89	2.48	2.30	2.76	1.33	1.36	1.01	0.94	1.16
Means for species	2.01	1.71	1.52	1.03	—	2.58	2.43	2.26	1.83	—	1.26	1.21	1.07	0.87	—
Difference for significance (P=0.05) in comparison of:															
Means for species			0.14					0.18					0.19		
Means for stages			0.05					0.03					0.08		

*Not included in analysis of variance; yields for 4 years only.

lower than those of series II with which they were combined. This would be expected in view of the fact that the yields from series I were obtained in the second year after seeding and therefore under conditions less favorable to pure grass stands than those of series II.

TABLE 4.—*Analysis of variance for species, stages, and years as given in Table 3.*

Variation due to	Yields at first cutting, "hay" stages		Yields from all cuttings, all stages		After effect of cutting treatments	
	Degrees of freedom	Variance	Degrees of freedom	Variance	Degrees of freedom	Variance
Years	4	6.995**	2	3.624**	1	0.025
Blocks	15	1.561**	7	0.662*	6	0.733*
Species	2	4.842**	3	6.312**	3	1.520**
Species × years	8	0.756**	6	0.816*	3	0.787*
Error "A"	30	0.163	21	0.236	18	0.196
Stages	3	4.915**	5	14.822**	5	0.313**
Stages × years	12	0.119**	10	0.582**	5	0.039
Stages × species	6	0.784**	15	0.617**	15	0.079**
Stages × species × years	24	0.168**	30	0.266**	15	0.027
Error "B"	135	0.023	140	0.006	120	0.024

*Significant at P = 0.05.
**Significant at P = 0.01.

A comparison of the means for stages shows a significant increase for each successive stage later than the beginning of heading when the yields of brome grass, timothy, and red top are combined. Although Kentucky bluegrass has not been included in the analysis of variance it shows a similar trend. When the three species referred to above are considered individually there are only two cases where the yield is not significantly superior to that of the preceding stage, *viz.*, timothy at stage 5 and red top at stage 6.

A comparison of the means for species shows superiority for brome grass, the highest yielding species of the group. Timothy is significantly superior to red top, while Kentucky bluegrass is the lowest yielding species. If the first three species are compared within the same stage, it is found that there are no significant differences at stage 3, beginning of heading, but brome grass is significantly superior to all other species at all the remaining stages. Timothy is significantly superior to red top only at stage 6.

YIELDS FROM ALL CUTTINGS, ALL STAGES

Yields obtained from two or more cuttings made at each of six stages of growth for the four grass species in series II are tabulated in the second section of Table 3. A comparison of the means for stages shows a significant increase for each successive stage as far as stage 4, beginning of bloom, when the yields of the four species are combined. Beyond this stage the increases are not significant.

When the four species are considered individually, there is also an increase in yield with each successive stage as far as stage 4, but thereafter no consistent trend is shown. Red top actually shows a significant decline in yield beyond this stage.

A comparison of the means for species shows that, although brome grass under these conditions is still a high-yielding species, its superiority over timothy does not reach the 5% level of significance. The yields of timothy and red top are not significantly different from one another, while Kentucky bluegrass is, again, the lowest yielding species of the group. When the four species are compared within the same stage, it is of interest to note that, under the conditions of this experiment at least, there is no significant difference in the yielding ability of the four species at stage 1, short grass. Kentucky bluegrass is a significantly lower yielding species than the others at stages 2, 3, and 4, beyond which the yields of red top decline to such an extent as to render the differences between this species and Kentucky bluegrass of no significance. The other two species, brome grass and timothy, continue significantly superior to Kentucky bluegrass at the later stages. Brome grass is significantly superior to red top from stage 4 onwards and significantly superior to timothy at stage 6. While there is no significant difference in yield between timothy and red top at any stage under the conditions of this experiment, it is perhaps worthy of note that the yields of timothy are higher at five of the six stages.

AFTER EFFECT OF CUTTING TREATMENTS

It might be expected that such diverse cutting treatments, as those employed in this study would have some influence upon the yields of hay obtained in the following year from the same plots. In order to measure such an after effect, all the plots of each species in series II were cut simultaneously in the late bloom stage for each species in 1940 and 1941. The yield data obtained measure the after effect of the six regular cutting treatments in 1939 and 1940, respectively, and are shown in the last section of Table 3.

When the mean yields of the four combined species following the six different cutting treatments are compared, it is noted that significant depressions in yield follow the treatments made at the "grass" stages, 1 and 2, as compared with those made at the later "hay" stages. The after effect, however, varies greatly with the different species as one might expect, having in mind their differences in habit of growth. The low-growing species, red top and Kentucky bluegrass, are scarcely influenced by the varied cutting treatments, whereas the taller growing species, timothy and brome grass, show much less tolerance of the frequent cutting treatments given at stages 1 and 2. Cuttings made at stage 4, beginning of bloom, appear to have had a more favourable after effect upon the yields of brome grass and red top than other cutting treatments employed in this study.

A comparison of the means for species again reveals Kentucky bluegrass as a low yielder, but mean yields of the other three species are not significantly different.

CRUDE PROTEIN

Nitrogen determinations were made in the Chemistry Department of Macdonald College on samples from all cuttings of all treatments employed in series I in 1936 and from those of series II in 1937. Essentially similar results were obtained in the two years. The calculated percentages of crude protein ($N \times 6.25$) of these samples on a dry basis for the year 1937 are shown in Table 5.

All species show a marked decline in percentage of crude protein during the first three stages, which is to be expected as a result of a period of rapid stem elongation. When the four species are compared with respect to their crude protein content, it is noted that the differences between them are small in comparison with differences between stages of cutting within species.

An important seasonal influence upon percentage of crude protein is shown in the first section of Table 6, where a comparison is made of the crude protein content on a dry basis of six clippings from the four species of grasses at stage 1, short grass, during the season of 1937. All species show a midsummer depression in percentage of protein.

The yields of crude protein per acre for all cuttings of the four species in 1937 have been calculated and are presented in Table 7. In this year, brome grass gave the highest yield of crude protein per acre, red top and timothy were intermediate, and Kentucky bluegrass was the lowest of the group. Timothy appeared to reach its peak of protein yield at an earlier stage than the other three species. The highest mean yield of crude protein from the four species was obtained from the cutting treatment at stage 4, beginning to bloom.

CAROTENE

Carotene determinations were also made in the Chemistry Department on a complete set of the cuttings taken at all six stages from the four species, series II, in 1939. These determinations were made by the method of Guilbert (5), using 2-gram samples of the fresh herbage and employing an Evelyn photoelectric colorimeter with 440 μm filter for measuring the color of the final carotene solutions.

The carotene content in milligrams per 100 grams of dry matter for all clippings made at stage 1, short grass, is presented in Table 6. On the basis of the mean carotene content for the five clippings made during the season, it will be observed that brome grass ranks highest among the four species. Kentucky bluegrass, however, is the leading species at the last clipping date, September 29. It may also be noted that the general seasonal trend in carotene content of clippings made at this short-grass stage in 1939 bears a fairly close relationship to the seasonal trend in crude protein content shown for the season of 1937 in the same table.

The carotene content on a moisture-free basis for the first cuttings made at six different stages of growth in 1939 is presented in Table 5. Here again it will be noted that the trend in carotene with the various stages in 1939 shows a fairly close relationship to the trend in crude protein for these same stages in 1937.

TABLE 5.—*Crude protein and carotene content, on dry basis, of four grasses at six stages of cutting, Series II.*

Stage of cutting	Percentage of crude protein, 1937					Carotene, MG/100 grams, 1939				
	Brome grass	Timothy	Red top	Kentucky bluegrass	Means of 4 species	Brome grass	Timothy	Red top	Kentucky bluegrass	Means of 4 species
1, short grass	16.60	16.08	16.90	15.30	16.22	52.5	47.4	49.8	46.4	49.0
2, long grass	14.96	13.99	11.59	13.42	13.49	36.0	33.6	37.7	32.2	34.9
3, begin to head	11.22	8.15	8.17	11.61	9.79	18.9	19.4	19.2	32.2	22.4
4, begin to bloom	7.40	6.19	7.14	8.49	7.30	18.9	10.4	20.7	26.2	19.0
5, end of bloom	6.00	5.25	6.23	7.35	6.21	16.2	10.9	12.9	19.0	14.7
6, seed formed	6.12	4.38	6.36	7.44	6.07	15.6	7.5	13.2	16.5	13.2
Means	10.38	9.01	9.40	10.60	9.85	26.3	21.5	25.6	28.7	25.5

TABLE 6.—*Crude protein and carotene content, on dry basis, of four grasses clipped at stage 1, short grass, Series II.*

Percentage of crude protein at six intervals, 1937						Carotene, MG/100 grams, at five intervals, 1939					
Cutting date	Brome grass	Timothy	Red top	Kentucky bluegrass	Means of 4 species	Cutting date	Brome grass	Timothy	Red top	Kentucky bluegrass	Means of 4 species
May 21	16.6	16.1	16.9	15.3	16.2	May 20	52.5	47.4	49.8	46.4	49.0
June 1	21.1	17.7	21.8	18.6	19.8	June 1	41.8	38.1	26.8	19.3	31.5
June 24	16.8	14.1	14.8	13.5	14.8	June 19	41.2	29.7	43.7	39.0	38.4
July 27	15.6	12.6	14.6	13.9	14.2	July 25	29.7	13.5	29.8	25.9	24.7
Aug. 23	20.1	14.8	15.6	15.9	16.6	Sept. 29	36.2	24.2	33.7	43.4	34.4
Sept. 9	18.5	14.9	14.6	15.7	15.9						
Means	18.1	15.0	16.4	15.5	16.3	Means	40.3	30.6	36.8	34.8	35.6

In contrast with differences within species at the various stages of cutting used in this study, differences between species in carotene content may be considered quite small, especially in the earlier stages. In the more mature stages the carotene content of Kentucky bluegrass is maintained at a rather high level as compared with the other species, especially timothy.

Yields of carotene in pounds per acre for all cuttings at all stages of the four species in 1939 have been calculated and are presented in Table 7. On the basis of the yields obtained in this particular year, brome grass and red top have given relatively higher yields of carotene than the other two species. The highest mean yield of carotene per acre from the four species has been obtained from cutting treatments at the two "grass" stages. The decline in carotene yield from cutting treatments made at successively later stages has been particularly marked in timothy.

DISCUSSION

When the yielding ability of all four species is considered, brome grass shows superiority when cut at the advanced stages of maturity but not at the immature stages. Possibly better results would have been obtained with this species if the cuttings at stages 1 and 2 had not been made so close to the ground level. Brome grass is not generally regarded as a species which is tolerant of close-clipping or grazing and this may account for its less favorable performance at the immature stages. On the other hand, the drought resistance of this grass enables it to continue growth at levels of soil moisture which greatly restrict the growth of the other three species involved in this study. Its earlier maturity, moreover, enables it to pass through its later "hay" stages under more favorable soil moisture conditions than usually obtain for the later maturing species, timothy and red top.

Kentucky bluegrass has proved inferior in yielding ability to the other three species under these conditions.

On account of wide variations in soil, seasonal, and regional conditions, the relative yielding ability of the four species may be expected to vary greatly from year to year and from place to place. The yield data presented above may therefore have a rather limited and local significance.

Since the study has been made with pure species alone, special care has been taken to maintain the plots free from volunteer species, including weeds. Furthermore, no attempt has been made to determine the influence of any associated legume upon the relative yielding ability or protein content of the different species.

There is a marked upward trend in the yield of all four grasses at first cutting for all stages up to stage 4, the beginning of bloom. Beyond this stage, however, such increases as are shown are of a small order. Even the inclusion of later cuttings to obtain the total seasonal yield for each stage does not change the general trend, although it diminishes the differences in yields from the various cutting treatments to some extent.

TABLE 7.—*Yield of crude protein and carotene from all cuttings of four grasses at six stages, Series II.*

Stage of cutting	Crude protein, 1937, pounds per acre					Carotene, 1939, pounds per acre				
	Brome grass	Timothy	Red top	Kentucky bluegrass	Means of 4 species	Brome grass	Timothy	Red top	Kentucky bluegrass	Means of 4 species
1, short grass	408	338	386	284	354	0.893	0.870	0.970	0.834	0.892
2, long grass	484	400	406	334	406	0.973	0.781	1.226	0.684	0.916
3, begin to head	480	408	392	292	394	0.826	0.758	0.798	0.662	0.761
4, begin to bloom	598	374	434	360	442	0.974	0.534	1.030	0.804	0.835
5, end of bloom	486	342	438	336	400	0.910	0.612	0.741	0.775	0.759
6, seed formed	506	302	398	346	388	0.965	0.449	0.708	0.707	0.707
Means for species	494	362	410	326	398	0.923	0.667	0.912	0.744	0.812

Coincident with the marked upward trend in yield with the first four stages of cutting is a marked downward trend in percentage of crude protein in all four species. The peak in crude protein yield per acre appears to be reached at an earlier stage with timothy than with the other three species. This early peak in protein yield of timothy has already been noted by Evans, *et al.* (2)

A comparison of the variances, presented in Table 4, reveals highly significant interactions for stages × years, stages × species, and stages × species × years. There are also significant interactions for species × years. This would infer that yields obtained at the different stages used in this study differ greatly in different years and with different species. Furthermore, stages × species interactions are not similar from year to year, neither is the relative performance of different species the same from year to year. The importance of such interactive effects in a study of this kind is therefore indicated. Stage-of-cutting results obtained with one grass species cannot be applied unreservedly to another and results obtained at any single stage or with any single species in one year cannot be applied without reservations to other years.

In spite of the interactions noted above, comparative F values, summarized in Table 8, indicate highly significant differences for stages over and above the interactions in which they are involved. Significant differences are also shown for species over and above the interaction for species × years.

TABLE 8.—*Summary of F values for variances presented in Table 4.*

For comparison of	First cutting	All cuttings	After effect
Species with species × years	6.40*	7.73*	1.93
Stages with stages × years	41.3**	25.5**	80.8**
Stages with stages × species	6.27*	24.0**	39.2**
Stages with stages × species × years	29.2**	55.8**	11.7**
Stages × years with stages × species × years	0.71	2.19*	1.45
Stages × species with stages × species × years	4.67**	2.32*	2.97*

*Significant at P = 0.05. **Significant at P = 0.01.

If the mean 5-year yields for brome grass, timothy, and red top as presented in Table 3 are corrected for the mean influence of both stages and species, the interactive effect of individual stages × species may be shown by the mean deviations for each stage and species from the mean yield of all three species at all four stages, as in Table 9. Compared with the other two species, brome grass is significantly lower yielding at stage 3 while red top is significantly higher yielding at this stage. However, at stage 6 the situation is completely reversed, with brome grass the higher yielding and red top the lower yielding species. Timothy occupies an intermediate position, being superior to brome grass and inferior to red top at stage 3 and inferior to brome grass but superior to red top at stage 6, as judged by the 5% level of significance.

TABLE 9.—*Mean deviations after correction for mean influence of stages and species in Table 3, yields at first cutting, "hay" stages, 5-year mean, 1935, 1936, 1937, 1939, 1940.**

Stage of cutting	Brome grass	Timothy	Red top
3, begin to head	−0.305	+0.060	+0.246
4, begin to bloom	+0.065	−0.026	−0.039
5, end of bloom	+0.090	−0.070	−0.019
6, seed formed	+0.149	+0.036	−0.186

*Difference for significance (P = 0.05) in comparison of deviations 0.088.

SUMMARY

Brome grass, timothy, red top, and Kentucky bluegrass were compared at six different stages of growth, *viz.*, short grass, long grass, beginning of heading, beginning of bloom, end of bloom, and when seed had formed.

When the yields of all cuttings were added together so as to obtain a total seasonal yield for each stage, the combined yields of the four species showed a significant increase with each successive stage as far as the beginning of bloom, after which the increases in yield were not significant.

When the yields at first cutting for the four "hay" stages were compared, the combined yields of brome grass, timothy, and red top showed a significant increase with each successive stage later than the beginning of heading.

Brome grass was the highest yielding species of the group, under these conditions, Kentucky bluegrass was the lowest, while timothy and red top occupied an intermediate position.

The percentage of crude protein decreased with each successive stage of cutting. The decline was more rapid, however, during the earlier stages coincident with a period of rapid stem elongation. The peak of crude protein yield for the four species combined was reached at the beginning of bloom. Brome grass gave the highest yields of crude protein per acre. Timothy appeared to reach the peak of its protein yield at an earlier stage than the other three species under these conditions.

The carotene content also declined with successively later stages of cutting. Differences between species were small when compared with differences within species, especially in the earlier stages. At the more mature stages Kentucky bluegrass maintained a relatively higher and timothy a relatively lower level of carotene content than the other two species.

Highly significant interactions were obtained for stages × years, stages × species, and stages × species × years.

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"NATURAL CROSSING" OF WHITE CLOVER BY BEES[1]

SANFORD S. ATWOOD[2]

ALTHOUGH an understanding of the mode of pollination is generally considered a prerequisite to the intelligent planning and pursuing of a profitable breeding program, detailed information on this subject has not been available previously for white clover (*Trifolium repens* L.). It has long been recognized, however, that honey bees are the most common pollinating insects for white clover and that seed set in the open is usually good if pollination has been adequately effected under proper environmental conditions. Since it was also known that most clones of white clover are self-sterile (9, 7, 2),[3] it has generally been assumed that the species should be classed as naturally cross-pollinated under most circumstances. Though this assumption may hold for the majority of clones, the present study shows that it certainly does not apply to those bearing the self-compatibility factor (4).

An important consideration in any study of this kind is the selection of typical clones to be tested, especially if different degrees of self-compatibility occur within the species. This is particularly true with white clover, where genetically distinct types have been demonstrated, ranging from almost complete self-incompatibility (1) through all intermediate grades of pseudo-self-compatibility (3) to very high degrees of true self-compatibility (4). Since all except the clones with the lowest seed-setting ability following self-pollination have been useful in establishing inbred lines, it seemed desirable to learn how the different degrees of self-compatibility might affect the ultimate combining of selected plants.

The best measure of natural crossing is obtained when clones differing in an easily recognized genetic character are allowed to cross in the open. By classifying the progeny obtained from the recessive parent, a direct measure of the amount of crossing is secured. This procedure demands adequate isolation to prevent crossing between any except the selected clones, but in the case of white clover isolation is difficult to find. Since many insects besides honey bees visit white clover and since the species is practically omnipresent near cultivated areas, isolation was obtained in the present study by the use of cages placed over the selected clones increased vegetatively in the field for this purpose.

MATERIALS AND METHODS

The two clones selected as males[4] for the crosses in this study were homozygous, respectively, for two dominant genetic markings, purple leaf color and V-shaped

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[1]Contribution No. 54, of the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, State College, Pa., in cooperation with the northeastern states. Received for publication April 26, 1943.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 869.

[4]All normal flowers of white clover are perfect, but for convenience in reference the seed parent will be considered as the female and the pollen parent as the male.

white marking on the leaf blade. Both markings are inherited as simple Mendelian dominants, and both are easily classified in the seedling stage.

One of the nine clones selected as female showed a high degree of self-compatibility. This was the same clone as the male parent (9–II) used in a previous study of the genetics of self-compatibility (4). The other eight females ranged from high to low pseudo-self-compatibility and were selected because they were parents or potential parents of inbred lines. Inbreeding has been continued into the second generation from four of the parents, and as far as production of selfed seed was concerned all lines could have been continued. The plant with the highest degree of pseudo-self-compatibility (plant B, Table 1) was used previously as the female parent (2-1) in a genetic study of this character (3).

The method of using bees for crossing under cages was the same as outlined previously (2). The individual cuttings, however, were surrounded by 2×2 foot wooden frames extending about 3 inches above the surface of the soil in order to prevent intermingling of the stolons and flower heads from the two clones in each cage. In this way it was possible to include a total of eight cuttings within each 4×8 foot cage. Four of the cuttings under each cage were of the same male parent clone, and these were arranged in alternate positions with the four cuttings of one recessive female. The plants were caged in the flush of bloom during June and July of their second summer in the field, and ripe seed was harvested soon after removing the cage in late July or early August. For classification the seedlings were grown in flats in the greenhouse each year during October and November.

In analyzing for covariance, the procedure suggested by Snedecor (8) was followed.

EXPERIMENTAL RESULTS

SELF-COMPATIBILITY OF CLONES

Considerable variation has always been noted in measuring the degree of self-compatibility for any clone of white clover. The number of selfed seeds varies widely not only between different cuttings of the same clone, but also between different heads on a single cutting. The difference between years is often great, but significant interannual correlations are generally obtained, even with pseudo-self-compatible clones (3). The nine female clones used in this study have been self-pollinated under bags in the field for four or five years, but only the results for 1942 are presented (Table 1). The average for each clone is based on 23 to 50 heads harvested from three to five cuttings. Although the seed set for clone A (75.4) is considerably lower than that obtained in previous years (e.g., 159.3 in 1940), this clone exhibits much greater self-compatibility than the others. Since, in addition, clone A possesses the S_f allele which none of the other clones have, it has not been included with the others when analyzing for inter-clone differences.

The other eight female clones varied from an average of 15.2 seeds per head to 0.2. When the variance between clones was compared with that within clones, a highly significant F value was obtained. Here, likewise, the averages were lower than in some previous years, but the order of the different clones was much the same, at least for those showing significant differences.

TABLE 1.—*Summary of seeds per head from selfing, seeds per head obtained under bee cages, percentage germination of the latter, and percentage crossing for nine plants of white clover enclosed under 23 cages during two years.*

Clone No.	No. of seeds per head from selfing	Cage No.	Year caged	♂ marking	No. of seeds per head (tested heads)	Germination, %	Total plants classified	Crossing, %
A	75.4	1	1942	P*	147.1	60.4	2,418	18.8
B	15.2	2	1941	V*	101.7	65.7	887	85.0
		3	1942	V	19.4	82.8	1,325	89.2
		4	1942	V	54.3	62.8	856	91.7
		5	1942	P	53.3	50.3	677	92.3
C	6.2	6	1941	V	103.0	46.4	788	100.0
		7	1942	V	20.1	76.1	1,213	97.6
		8	1942	V	53.6	58.1	819	99.0
		9	1942	P	68.9	55.8	800	99.6
D	3.5	10	1941	V	73.2	67.1	1,006	99.4
		11	1942	V	19.0	86.9	1,024	98.5
		12	1942	V	18.4	82.9	982	98.8
		13	1942	P	55.9	70.3	764	100.0
E	3.1	14	1941	V	53.8	58.4	1,139	98.3
		15	1942	P	12.3	90.6	649	96.1
F	2.8	16	1941	V	74.5	66.5	1,330	98.5
		17	1942	P	55.8	51.0	749	96.8
G	1.5	18	1941	V	71.9	55.8	1,089	98.9
		19	1942	P	10.0	78.7	590	89.5
H	0.9	20	1941	V	115.7	72.8	1,455	99.8
		21	1942	P	65.6	72.2	1,040	99.2
I	0.2	22	1941	V	57.2	58.4	1,139	99.8
		23	1942	P	14.8	72.6	385	98.2

*P = purple leaf; V = V-shaped white area on leaf blade (see text).

The purple- and white-marked male clones averaged 5.0 and 19.1 seeds per head when selfed under bag at the same time as the females, but from previous crosses in the greenhouse (3) it was thought that such differences as this in pseudo-self-compatibility of the males would not influence their relative ability to effect cross-pollination when mated with unrelated females.

AMOUNT OF CROSSING

In order to measure the percentage crossing of the different female clones, 23,124 seedlings were classified, the number for different cages varying from 385 to 2,418. The most striking feature of the results was the fact that percentage crossing for different cages varied from 18.8 to 100.0. Since clone A, which bore the S_f allele, crossed only 18.8%, it could be classed as an "often cross-pollinated" plant. The question arises whether the percentage crossing should be doubled for clone A in order to account for sibbing which might have taken place within the cage. This procedure is regularly used with the self-fertile, naturally self-pollinating cereals, and in some respects clone A behaves in a similar manner. Its high degree of self-compatibility following bee pollination was noted in the 1940 seed set (2) when an average of 173.7 seeds per head was obtained

from this clone caged by itself. Although it is not as highly autogamous as some other clones of white clover, it has regularly set selfed seed without artificial pollination when isolated in both greenhouse and field. Furthermore, a total of 758 heads were produced on plant A, and at certain times during the flowering period they may have been slightly more numerous than those on the male parent. From this latter factor one might feel justified in assuming that the bees would carry pollen to a head on clone A just as frequently from another head on the same clone as from a head on the male parent. Consequently, to double the percentage crossing might give a better estimate for the crossing potentialities of a single isolated cutting.

In this sort of adjustment of percentage crossing, it is also necessary to assume that there would be equal chances for fertilization when pollen from two clones was mixed on the stigma. From a genetical study, however, of the S_f allele (4 and unpublished data), it has been shown that pollen bearing S_f does not compete equally well with pollen bearing other alleles when the two are applied together. It has also been shown that the second factor carried in a heterozygous self-compatible clone has an inhibiting influence on pollen bearing the same allele. In other words, both types of pollen produced by an S_fS_x clone such as A should be at a disadvantage when growing on their own stigma in competition with pollen bearing unrelated alleles. The only way one could obtain 81.2% selfing and 18.8% crossing, therefore, would be to have a large excess of self pollen over cross pollen on the stigmas of clone A. Assuming that for most of the time there were approximately equal numbers of flowers on both clones under the cage, there are at least two explanations for the high amount of selfing. Either the bees tended to move more among the cuttings of A than at random between the two different clones, although this was not evident from watching the bees, or they failed to carry enough pollen from the purple male to cross adequately all flowers visited on a single trip to the A heads. It is quite possible, therefore, that under other conditions a much higher percentage crossing would be obtained, and that 18.8% should be considered closer to a minimum rather than a maximum estimate for this self-compatible clone.

Evidence that varying amounts of crossing could be secured under other conditions was obtained from an analysis of the variation within this cage. The 4,000 seeds used for the test were chosen by taking 100 at random from each of 10 good heads harvested on each of the four cuttings. Considerable variation was obtained not only between heads but also between cuttings (Table 2), and an analysis of variance showed the differences between cuttings to be highly significant. When these differences were adjusted by covariance to a common basis in regard to either seeds per head or percentage germination, the F value was lowered from 5.48 to 4.56 and 5.12, respectively, but the differences were still highly significant. An explanation of these differences between cuttings may perhaps be found in the behavior of the bees. The hive was located at the end of the cage near cutting 1, and the percentage crossing decreased

continuously from this end to the other (Table 2). It was noticed that the bees did not fly directly to a flower head on leaving the hive; instead most of them flew to the top of the cage for some time before dropping to the flowers. Since the prevailing winds often carried the bees to the end of the cage with cutting 4, it is reasonable that this cutting should be crossed the least, and that as the bees moved back toward the hive, they gathered more male pollen and consequently effected a higher percentage crossing. Similar gradients were observed in some other cages, but the differences were often small and in most of them there was no adequate test of significance.

TABLE 2.—*Variation in percentage crossing obtained from different heads of plant A.*

Cutting No.	Percentage crossing		
	Maximum	Minimum	Average
1	44.8	8.3	25.5
2	39.4	7.8	25.0
3	39.6	8.0	19.5
4	14.5	5.4	9.8

The percentage crossing obtained with the eight pseudo-self-compatible clones was very much higher than that with clone A (Table 1), the different cages varying from 85.0 to 100.0%. There appeared to be a slight inverse relationship between the amount of pseudo-self-compatibility and the amount of crossing. The clone with the highest seed set crossed the least and the clone crossing the most was next to lowest in seed set, but the correlation coefficient was not significant ($r = -0.026$). In order to test significance of differences between clones in amount of crossing, the data were grouped in two ways. In the first place, since each clone was caged at least once in each year, these 16 comparable cages were considered together and the clone differences tested by clones × years interaction. Secondly, since three of the clones were replicated using three cages each during 1942, these nine cages were considered together and the differences tested by clones × replications interaction.

With the eight clones caged both years, neither the difference between clones nor between years was significant. When the clone differences were adjusted by covariance, however, to a common basis in regard to percentage germination (Table 3), the F value was raised from 2.71 to 5.06, a significant value. A similar adjustment for seeds per head lowered the F value to 2.36. The differences between clones in percentage germination were not significant, but those in seeds per head were highly significant.

With the second method of summarizing using only the three clones replicated in 1942, the differences between clones were highly significant and those between replications were significant. After adjusting the clone differences to a common percentage germination (Table 4) or number of seeds per head by covariance, the F value

TABLE 3.—*Analysis of covariance for percentage germination (x) and percentage crossing (y) among eight pseudo-self-compatible plants enclosed under bee cages during two years.*

Source of variation	D. F.	Sums of squares and products			Correlation coefficient	Regression coefficient	Errors of estimate		
		Sx^2	Sxy	Sy^2			Sum of squares	D. F.	Mean square
Plants	7	776.90	122.45	257.45	0.2730	0.1577	—	—	—
Years	1	108.68	−22.67	4.73	—	−0.2086	—	—	—
Error	7	830.57	−191.98	95.01	−0.6815	−0.2311	50.64	6	8.44
Total	15	1716.16	−92.20	357.19	−0.1178	−0.0537	—	—	—
Within cages	44	5478.00	685.05	645.07	0.3641*	0.1251	—	—	—
Plants+error	14	1607.47	−69.53	352.46	—	—	349.45	13	—
Difference for testing adjusted plant means							298.81	7	42.69†

*Significant according to Fisher's (5) table V, A.
†F = 5.06, exceeding odds 20:1.

was raised from 285.45 to 429.23 and 446.50, respectively. The differences between clones were not significant for either percentage germination or seeds per head.

TABLE 4.—*Analysis of covariance for percentage germination (x) and percentage crossing (y) among three pseudo-self-compatible plants each enclosed under three replicated bee cages in 1942.*

Source of variation	D. F.	Sums of squares and products			Correlation coefficient	Regression coefficient	Errors of estimate		
		Sx^2	Sxy	Sy^2			Sums of squares	D. F.	Mean square
Plants	2	470.21	121.10	130.96	0.4880	0.2575	—	—	—
Replication	2	836.51	−74.33	6.68	−0.9940	−0.0889	—	—	—
Error	4	159.49	−9.18	0.92	−0.7581	−0.0576	0.39	3	0.13
Total	8	1466.21	37.59	138.56	0.0834	0.0256	—	—	—
Within cages	25	1925.75	108.93	70.20	0.2963	0.0566	—	—	—
Plants+error	6	629.70	111.92	131.88	—	—	111.99	5	—
Difference for testing adjusted plant means							111.60	2	55.80*

*F = 429.33, exceeding odds 99:1.

It might appear from the change in F values that consideration of the second variable was very worthwhile. When the reduction in error due to correction by regression was calculated, however, no significant effect was found for any of the four analyses described for these eight pseudo-self-compatible clones. Likewise, little relationship was shown between the pairs of characters either by the correlation coefficients or the regression coefficients. Only in the

case of correlation between percentage germination and percentage crossing for within cages (Table 3) was the value of r statistically significant. In all but one case, on the other hand, considerable change in rank for the adjusted mean percentages of crossing was observed. The adjustment makes the measure of crossing more precise, and since little extra work is involved in recording either seeds per head or percentage germination, it might be concluded that retention of these independent variables in similar experiments would be worth the trouble.

For each of the analyses there was also calculated the variance within cages in order to provide an estimate of the sampling error (6). Especially in the case of the eight clones caged both years (Table 3), this variance was fairly large in comparison with that attributable to clones, and it suggests that with this type of study several measurements should be made for each clone in order that the most accurate estimate of clone differences be obtained.

In 1941 the number of flowers on each head was also recorded. Since the variance between cuttings within cages was highly significant, its relationship to seeds per head was tested. The latter had shown significant differences both between cages and between cuttings. When the number of seeds per head was adjusted to a common basis in regard to flowers per head by analysis of covariance, the F values were lowered from 2.49 to 2.25 for cages and from 67.43 to 57.95 for cuttings. The former was now less than the 5% point (2.45), but the latter remained highly significant. The correlation coefficients for cages, cuttings, and total, respectively, were 0.74, 0.72, and 0.43, all of them significant. The reduction due to regression was significant for both cages and cuttings. Apparently, the number of seeds per head is in part a function of the number of flowers, but the latter does not account for all of the variation in the former.

DISCUSSION

In most species where percentage crossing has been investigated previously, all individuals within the species are of approximately the same degree of self-fertility and consequently show similar amounts of crossing. The situation is considerably different in white clover where different clones range from almost complete self-incompatibility to high degrees of self-compatibility. Although clones with different degrees of pseudo-self-compatibility show significantly different amounts of crossing, for most practical breeding purposes the amounts of crossing are of a similar high degree. It might be inferred that plants of this type could be combined adequately if allowed to intercross in isolation.

In regard to the self-compatible clone, however, a different breeding procedure seems necessary. Combining clones of this type would not give adequate amounts of crossing, and it would probably be necessary to eliminate the S_f gene by outcrossing before attempting to cross self-fertile lines. When the self-fertile plant was crossed under a cage, it was considered necessary to increase the percentage crossing in order to obtain the most valid estimate for a single isolated

plant. Under regular breeding circumstances, on the other hand, crossing would probably be attempted in somewhat the same manner as that used here, and an adjustment for possible sibbing serves no practical purpose.

The use of cages for this type of study has obvious disadvantages in comparison with natural crossing in the open. It was apparent that the flowers under the cage were being visited more frequently than those outside, and in several respects the behavior of the bees under the cage was not normal. On the other hand, the use of cages has the advantage of testing a larger number of clones under better controlled conditions. In addition, since it is possible to arrange clones under the cage in much the same manner as that which would be used for practical crossing, the results should have direct application.

The analysis of covariance proved a useful method of summarizing for these data. Significant differences in the adjusted means were demonstrable using covariance when the unadjusted means were not significantly different. Likewise, the ranking of the adjusted means was changed in several cases from the original order. The recommendation has been made (8) not to use covariance unless "there is a well-considered reason for doing so". The present study may be a borderline case, but since a certain gain in precision was noted, the little extra work in noting the independent variable would seem to be justified.

SUMMARY

When eight clones of white clover which differed significantly in degree of pseudo-self-compatibility and which were recessive for two marker characters were crossed under bee cages during two years with other clones homozygous for these markers, the percentage crossing ranged from 85.0 to 100.0 for different cages and was significantly different for the eight clones. A slight inverse relationship may exist between the degree of pseudo-self-compatibility and the amount of crossing. Increased precision was gained when the percentage crossing was adjusted by analysis of covariance according to number of seeds per head or percentage germination.

In the case of a self-compatible clone, the percentage crossing was only 18.8, but several lines of evidence suggested that this should be a minmum rather than a maximum estimate for the clone. Since such widely different amounts of crossing may be expected within the species, it is evident that all clones should be investigated thoroughly at least for their self-compatibility before including them in a breeding program.

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GROWTH OF STRAWBERRY CLOVER VARIETIES AND OF ALFALFA AND LADINO CLOVER AS AFFECTED BY SALT[1]

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IN RECENT years considerable interest has been shown in strawberry clover, *trifolium fragiferum*, because of its ability to grow under conditions of moderate salinity, and because of its applicability in the reclamation of water-logged, saline soils now considered as waste lands in the western United States (9, 13).[3] This legume, one of the more recent clover immigrants, is a perennial and native of eastern Mediterranean countries and of southern Asia Minor. It is believed to possess several advantages over alfalfa in that apparently it will tolerate more salinity (1, 11), will withstand flooding-over for as much as two months at a time (9), is shallow-rooted, and may be used to replace alfalfa when the prevalence of dwarf disease makes the growing of alfalfa no longer profitable or possible.

Kearney and Scofield (12) stated that strawberry clover, "is as tolerant of salinity as most of the native or introduced grasses, or even more tolerant". Ahi and Powers (1), working with sand and solution cultures, found that alfalfa and strawberry clover would tolerate 2,800 and 5,600 p.p.m. of salt obtained by diluting sea water, respectively. They concluded that, "strawberry clover was found the most promising resistant legume for salinity, followed by sweet clover, then alfalfa".

The Bureau of Plant Industry and others have made several introductions of strawberry clover and a number of strains have since been identified in the states ranging from Washington to Colorado. A comparison of some of these strains for their tolerance to salinity was suggested.[4] In order to compare the behavior of strawberry clover under saline conditions with other legumes, alfalfa and Ladino clover were included in these tests.

Alfalfa is the most widely grown forage crop in the western United States and, as in this study, is commonly included as a standard in tests of forage crops (11). Harris (7) cites considerable data on the tolerance of alfalfa to alkali, giving the maximum salt tolerated equal to 6,000 p.p.m. of sodium sulfate in the soil. More recently, in a survey (17) of salinity conditions in the Pecos River Valley of New Mexico and Texas it was found that alfalfa growing well where the soil solution extracts (extract from a soil at the saturation

[1]Contribution from the U. S. Regional Salinity Laboratory, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Riverside, Calif., in cooperation with the eleven western states and the Territory of Hawaii. Received for publication April 26, 1943.

[2]Assistant Physiologist and Director, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 879.

[4]Suggested by Dr. E. A. Hollowell, Senior Agronomist, Division of Forage Crops and Diseases, Washington, D. C.

point) had a conductance ($K \times 10^5 @ 25°$ C) of 800 and contained about 5,000–6,000 p.p.m. of salts in the extract. These salts were usually 50 to 60% sulfates and 30 to 50% chlorides. The soils in this region contain large quantities of gypsum. Harris (7) states further that, "the high resistance of alfalfa may be assigned to its deep feeding habits in many cases, the feeding roots not being in the alkali zone but being in the purer solutions below".

Ladino clover, *Trifolium repens*, var. Ladino, a perennial and a native of Italy, is presumed to be a large form of white clover. This crop is rapidly growing in popularity throughout the United States (2, 3, 10, 11, 14, 18, 19), and for irrigated pastures in California it ranks first in popularity and is being recommended in 37 of the 40 counties (11). The popularity of this plant for pastures rests mainly upon the quantity and quality of forage produced, its ability to recover rapidly following grazing or clipping, and the fact that all of its growth is leafy and succulent rather than stemmy. Though little is known of its salt tolerance, preliminary observations have led to the assumption that it is not a very salt-tolerant crop (11, 14).

MATERIALS AND METHODS

Selected California Common alfalfa seed was supplied by Dr. B. A. Madson, of the California Agricultural Experiment Station. Ladino clover seed (blue label) was obtained from The Grange Company, Oakdale, Calif. Seed of the following strawberry clover strains was obtained from the Bureau of Plant Industry:

FC No. 22,797 strawberry clover (Nebraska)
FC No. 22,798 strawberry clover (Colorado)
FC No. 22,800 strawberry clover (Washington)
FC No. 22,801 strawberry clover (Idaho)
FC No. 22,802 strawberry clover (Oregon)

Seedlings, 20 days old, were transferred to 5-gallon containers (four seedlings per pot) of automatically-operated sand culture equipment (6). By means of this equipment each pot received 2 quarts of solution once each hour from 7 a.m. to 7 p.m., inclusive, with one additional delivery at midnight. With the daily addition of distilled water into the 5-gallon solution reservoir to replace water lost by evaporation and transpiration, and by means of the frequent irrigations, the plants were subjected to a culture solution almost constant in concentration. Decreases in concentration caused by salt absorption by plants were negligible based on the volume of solution used.

Experimental design.—Studies made at the Regional Salinity Laboratory (5, 8, 15) have indicated that the reduction of plant growth in saline substrates is better correlated with the osmotic concentration of these substrates than with any other index of concentration. Accordingly this basis was chosen to represent the concentration of solutions in the present experiment. Besides a base nutrient treatment of 0.5 atmosphere osmotic concentration, three additional treatments of 2.5, 3.5, and 4.5 atmospheres were obtained by the addition of sodium chloride to the base nutrient solution.

For alfalfa there were three replications and for Ladino clover and each strain of strawberry clover two replications. There were 10 pots per table, and treatments were randomized on the six tables.

Culture solutions.—The composition of the culture solutions is given in Table 1.

TABLE 1.—*Composition of the culture solutions.**

Osmotic concentration, atmospheres	Ca	Mg	Na	K	Cl	SO_4	H_2PO_4	NO_3	HCO_3	$K \times 10^5$ @ 25°C
				Equivalents per million†						
0.5 (base nutrient)	5.9	2.7	2.1	3.25	1.8	4.3	0.75	7.0	2.1	154
2.5	5.9	2.7	50.1	3.25	49.8	4.3	0.75	7.0	2.1	662
3.5	5.9	2.7	74.1	3.25	73.8	4.3	0.75	7.0	2.1	918
4.5	5.9	2.7	98.1	3.25	97.8	4.3	0.75	7.0	2.1	1,142
				Parts per million						
0.5 (base nutrient)	118	33	47	128	64	20	74	434	129	154
2.5	118	33	1,152	128	1,766	20	74	434	129	662
3.5	118	33	1,704	128	2,617	20	74	434	129	918
4.5	118	33	2,256	128	3,468	20	74	434	129	1,142

*Micro-elements were added to all solutions as follows: Boron, 0.5 p.p.m. from boric acid; manganese, 0.5 p.p.m. from manganese chloride; and, iron, 0.5 p.p.m. from ferric citrate. The tap water used in making up solutions was alkaline, but the inclusion of nitric acid in the composition of the solution reduced the pH to an initial value of 5.7.

†"An equivalent per million (e.p.m.) is a unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing concentration in parts per million (p.p.m.) by the chemical combining weight of the substance or ion. This unit has also been called 'milli-equivalents per liter' and 'milligram equivalents per kilogram.' The latter term is precise, but the former will be in error if the specific gravity of the solution is not exactly 1.0." A.S.T.M. Standards, 1940; part III, page 541.

From April 27 until May 23, 1942, all pots received only base nutrient solution. On May 23, 46 days after seeding, the alfalfa was cropped for it had attained a height of 35–40 cm and was at the incipient flowering stage. Following this cropping of alfalfa, there was a removal and replenishment of two-thirds of the base nutrient solution in all units. After a lapse of 3 days to permit some recovery following cutting, salt treatment on all crops was initiated. Starting on May 26 the solutions were brought up to final concentration at the rate of 1 atmosphere osmotic concentration of sodium chloride per day.

Insect control.—The greenhouse was fumigated with Nicofume on May 7 and June 3, 1942, to control thrips on alfalfa. Although the fumigation was intense enough to produce some visible symptoms of injury to the plants, the thrips were not fully eradicated on the alfalfa.

Harvesting procedure.—Plants were harvested at incipient to early flowering stage. Alfalfa was cut 4 inches from the level of the sand, while the Ladino and strawberry clovers were cut off even with the top of the pot or container, i.e., at about the 1½- to 2-inch level. Immediately after harvesting and weighing, the plants were dried rapidly in a large, forced-draft, gas-heated oven and oven-dry weights were obtained.

TREATMENT OF HARVEST DATA

One of the most important considerations in a comparison of forage crops is total production of a forage within a growing season. Therefore, although there were three croppings of alfalfa (May 23, June 15, and July 13, 1942) and two croppings of the clovers (June 15 and July 13, 1942) during the elapsed time of the experiment (97 days), only the total yield for the "season" is reported.

This basis is also preferable owing to the fact that different crops reach their peaks in the production of forage after different lengths of time.

Owing to differences in moisture contents of the species studied, the yield data are given on the dry weight basis. The percentage dry matter in the tops was within the range expected for each of the three species studied and, with increase in the salt concentration of the substrate, the percentage dry matter in the tops tended to increase. Alfalfa showed this trend at the time of the first harvest, but at the second harvest there was no consistent trend in the percentage dry matter with treatment. At the second harvest the tops of alfalfa contained approximately 23.5% dry matter. At this later harvest, the tops of the strawberry clover strains from any one treatment had very similar percentages of dry matter, averaging 16.7, 18.3, 20.1, and 21.5 for the treatments 0.5 (B.N.), 2.5, 3.5, and 4.5 atmospheres osmotic concentration, respectively.

In the same order of treatments the values for Ladino clover were 16.7, 19.0, 20.3, and 22.6% dry matter, respectively. It is reported in the literature that the addition of sodium chloride to the substrate resulted in an increase in the dry matter content of barley tops (4), a decrease in that of tomato tops (8), and no change in the dry matter of tops of dwarf red kidney bean (20).

Yield data may be interpreted on an "actual weight basis" or on a "relative weight basis" in which the growth of each crop under the base nutrient treatment is taken as 100%. From an agronomic point of view the principal consideration is total weight of forage produced. However, with crops of diverse weights such as these the yield data must be converted to the relative basis in order to determine the differential response of the various crops and strains to a given series of treatments. Thus, both bases are useful and both will be used in the following discussion.

Owing to the more rapid early growth of alfalfa, there was a pre-salt treatment harvest on the 46th day of the experiment, May 23, 1942, which yielded 9.28 grams of dry matter per pot (standard error, 0.25 gram). This weight is not included in any of the following data inasmuch as all pots were still receiving only base nutrient solution at this time.

Harvest weights are based on the average yield per pot of four plants for the entire experimental period.

RESULTS

Combined dry weights of tops produced by the various crops at the different salt levels are shown in Table 2.

Pictures were taken of the crops just prior to the final harvest. The various strains of strawberry clover were so similar in appearance that the picture of the highest yielding Nebraska strain alone is shown, together with alfalfa and Ladino clover (Fig. 1).

DISCUSSION OF RESULTS

The principal purpose of this experiment was to compare the tolerance of various strawberry clover strains to salinity. In the selection of a forage crop for use on saline land, tolerance to salinity is necessary. Usually, salty lands have a high water table and may be water-logged. In addition to salinity tolerance the crop must often be able to withstand water-logged conditions. It is believed that strawberry clover has achieved its popularity because it is

moderately tolerant to salinity and in addition is highly tolerant of a high water table. In our greenhouse tests the experiment was not designed to test the latter factor.

TABLE 2.—*Dry weight in grams of tops of strawberry clover, alfalfa, and Ladino clover produced during 97 days of growth, April 7 to July 13, 1942.*

Osmotic concentration, atmospheres	0.5 (B.N.)	2.5	3.5	4.5	Strain or crop mean*
Strawberry clover strains:					
Nebraska	45.6	43.3	34.8	28.9	38.1
Idaho	45.6	40.5	27.5	22.4	34.0
Colorado	41.1	32.5	27.4	22.7	30.9
Washington	41.6	33.0	25.1	15.7	28.8
Oregon	36.8	30.6	24.3	19.4	27.7
Alfalfa†	61.1	45.4	38.9	32.8	44.5
Ladino clover	96.3	64.8	55.4	42.7	64.8

*Difference between any two mean weights of strawberry clover strains needed for significance at the 5% level, 4.22 grams; for significance at the 1% level, 5.76 grams.
†A pre-salt treatment harvest of 9.28 grams dry weight was made. This is not included in the totals of this table.

INTERCOMPARISONS OF STRAWBERRY CLOVER STRAINS

Dry weight of tops.—On the basis of actual yields, the Nebraska strain yielded significantly better than the Colorado, Washington, and Oregon strains, but its yield did not differ significantly from that of the second best Idaho strain. It is also evident from Table 2 that there was a highly significant difference in yield between any two treatments with the higher yield always in favor of the treatment with the lower concentration of salt.

Relative dry weight of tops.—Inasmuch as some strains made better growth than others under the base nutrient treatment, relative dry weights were calculated for comparing the response of the strains to salt treatment. On the relative basis there was a significant difference in yield only between the highest and lowest yielding strains, *viz.*, Nebraska *vs.* Washington.

INTERCOMPARISONS AMONG THREE HIGHEST YIELDING STRAINS OF STRAWBERRY CLOVER, ALFALFA, AND LADINO CLOVER

An average of yields from all treatments on an actual weight basis (Table 2) shows that alfalfa yielded 1.3 and Ladino clover 1.9 times as great a weight of tops as strawberry clover (average for the three highest yielding strains). These results are in agreement with the field observations on these crops as reported by Jones and Brown (11). They have observed that, except under certain special conditions, Ladino clover outyields strawberry clover, and that under conditions where Ladino clover does not survive, strawberry clover usually makes only a very sparse growth. From June 15 to July 13, 1942, the daily temperatures in the greenhouse were comparatively high (maximum daily temperatures averaging around 99° F), and there was undoubtedly a "lag" in the growth of the Ladino clover, as has been reported by Jones and Brown (11) for the growth of Ladino clover during

hot weather. They report that alfalfa is relatively unaffected by such periods of hot weather. However, despite the "relative" depression in the growth of this crop as compared with alfalfa and strawberry clover, on an actual yield basis Ladino clover yielded the greatest amount of forage.

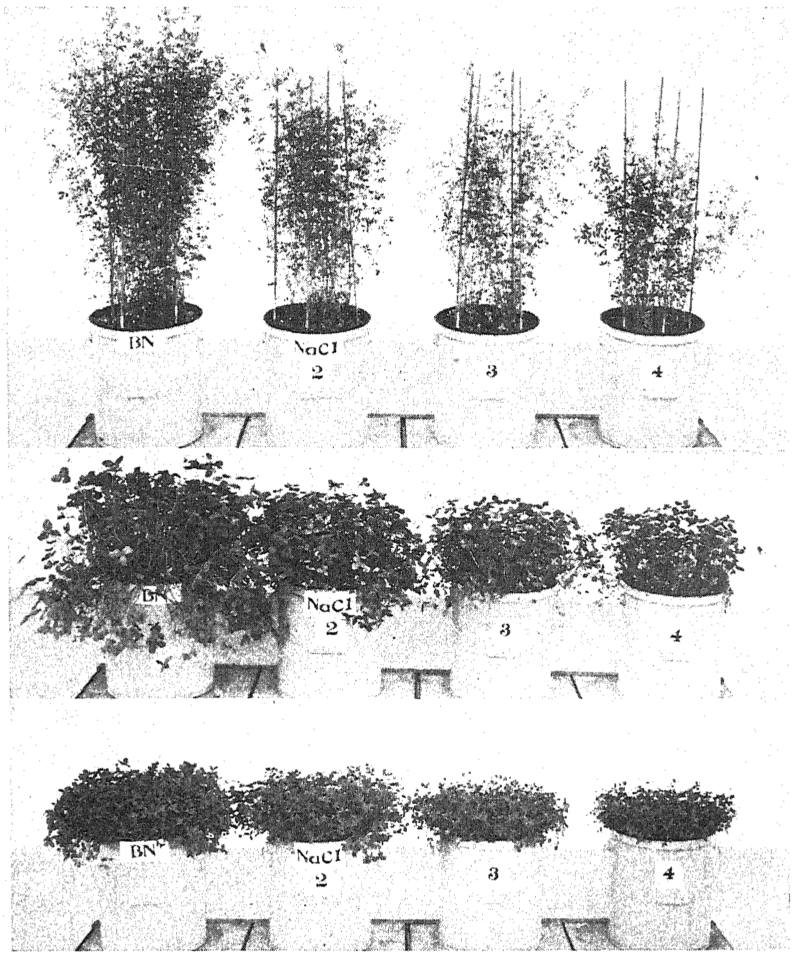

FIG. 1.—Appearance of plants at time of final harvest, July 13, 1942; 97 days from date of seeding. *Top*, alfalfa; *center*, Ladino clover; *bottom*, Nebraska strawberry clover. BN = base-nutrient; 2, 3, and 4 = number of atmospheres osmotic concentration of sodium chloride added to the base-nutrient solution.

Relative dry weight yields.—The relative dry weights of tops for the three best strains of strawberry clover, Nebraska, Idaho, and Colorado, and for alfalfa and Ladino clover are shown graphically in Fig. 2.

In preparing Fig. 2 data for the Washington and Oregon strains of strawberry clover were omitted so as not to make the graph too confusing. In a statistical comparison, including these two strains, the only significant difference in response at the 5% level was between the Nebraska strain and Ladino clover.

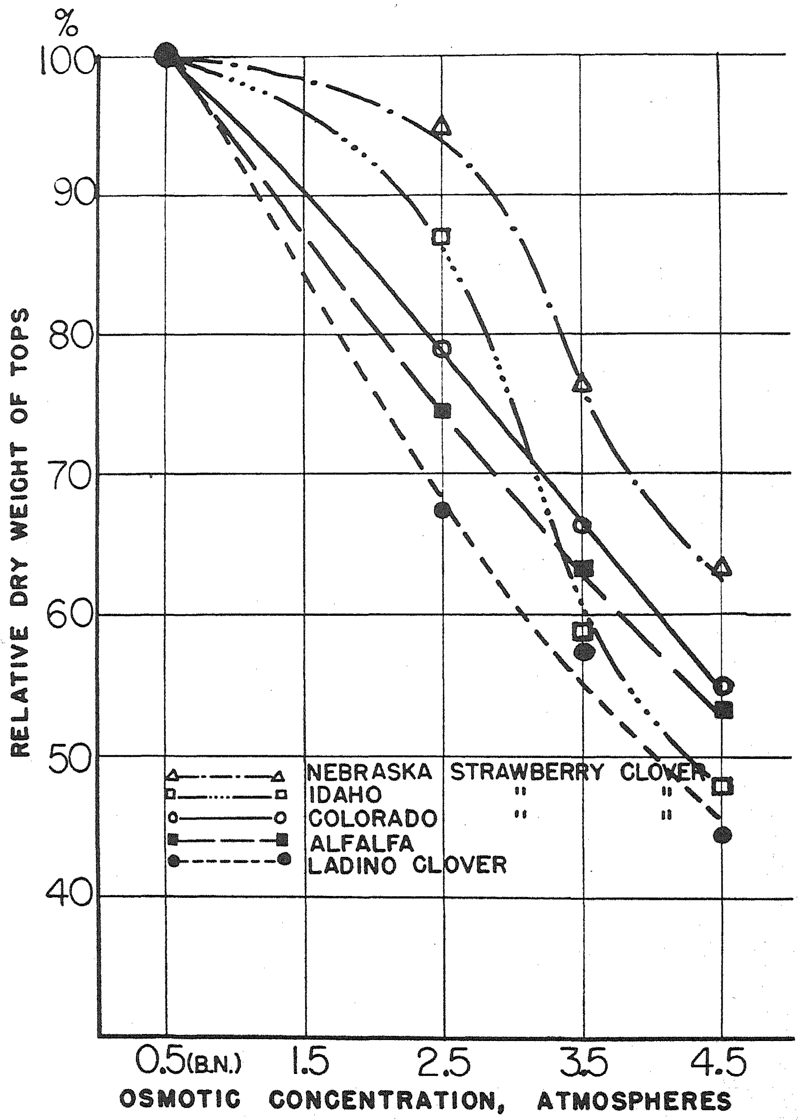

FIG. 2.—Relative dry weight of tops produced by the various strains of strawberry clover, alfalfa, and Ladino clover.

On a treatment mean basis involving the three best strains of strawberry clover, alfalfa, and Ladino clover, statistical analysis of the data showed that each increment of salt very significantly reduced the yield of tops.

RELATIONSHIP OF TESTS TO PRACTICAL AGRICULTURE

In view of the present demand for an increase in livestock production it seemed especially pertinent to study the response of several of the most important forage crops to salinity *per se*. In the selection of a forage crop, tolerance to salinity is, of course, only one of several important considerations. For example, it is generally agreed that one of the main virtues of strawberry clover is its ability to withstand not only a moderate amount of salinity but also a high water table and a water-logged condition of the soil. Our results show that *on a relative basis* only one of the five strains of strawberry clover, the Nebraska strain, was less affected by salt than either alfalfa or Ladino clover. However, despite the greater, relative salt effect on alfalfa and Ladino clover, *on an actual weight basis* these two crops yielded 1.3 and 1.9 times more forage, respectively, than did strawberry clover. Therefore, unless there are other important factors to consider such as unfavorable soil conditions, wherever Ladino clover or alfalfa can be established, these crops would generally be preferable to strawberry clover. The choice between alfalfa and Ladino clover rests on certain characteristics of the soil in question. Madson and Coke (14) state that in California alfalfa will usually outyield Ladino clover on the deeper and more porous soils, while on the more shallow and heavier soils Ladino will usually outyield alfalfa.

Recently, Magistad and Reitemeier (16) studied 17 representative western soils to determine the range of soil solution concentration and composition, and correlated these values with the observed plant growth. By means of the particular technic which they used, it was possible to obtain soil solutions at soil moisture contents near the wilting range, and possible errors in concentration and composition brought about by extrapolation back to field moisture contents were minimized if not altogether eliminated. Their data show the relationship between plant growth and soil solution concentrations in the wilting range. They give data showing that the concentration of soil solutions of saline soils may reach values of 40 atmospheres or more. At concentrations above three atmospheres plant growth was affected.

The range of salt concentrations used in the present study compare with concentrations of salt found in the soil solution of slightly saline soils by Magistad and Reitemeier (16).

SUMMARY

The relative yields and tolerances of five strains of strawberry clover, alfalfa, and Ladino clover to serial increases in the concentration of salt (NaCl) in the substratum were determined. The

concentration of the nutrient solution in the sand culture ranged from 0.5 to 4.5 atmospheres. The following results were obtained:

1. On an *actual yield basis*, alfalfa and Ladino clover yielded 1.3 and 1.9 times as much forage, respectively, as strawberry clover.

2. On a *relative basis* the Nebraska strain of strawberry clover was less affected by salt than alfalfa or Ladino clover. The differences in favor of the Colorado and Idaho strains and of alfalfa over Ladino clover approached significance at the 5% level.

3. Of the five strains of strawberry clover tested, the Nebraska strain yielded significantly better than the Colorado, Washington, and Oregon strains, but was not superior to the second highest yielding strain (Idaho).

4. On both the actual and relative yield bases there was a highly significant difference in yield between treatments, with the higher yield always in favor of the treatment with the lower concentration of salt.

5. There was no evidence that there is a given concentration of solution which may be regarded as critical, but rather there tended to be a linear relationship between growth reduction and increase in salt concentration of the solutions as expressed in atmospheres.

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ICE SHEET INJURY TO ALFALFA[1]

M. A. SPRAGUE AND L. F. GRABER[2]

ICE sheets which form and remain for extended periods in contact with the soil and crowns of alfalfa, clovers, and winter grains are among the most injurious of the climatic factors influencing the winter survival of such crops. The injuries may not only be severe, but they may occur over very wide areas. Ice sheets which are limited to local areas such as low spots in fields are of rather common occurrence, but sleet storms causing ice sheets over extensive areas are much less frequent in Wisconsin.

In February, 1937, sleet storms developed sheets of ice which covered most of the southeastern third of Wisconsin. Wall (8)[3] obtained information from 500 farmers in this ice-coated region as to the nature and duration of the ice sheets and the resulting losses in terms of the survival of alfalfa fields. He found that the stands on 237,000 acres (about one-fifth of the total acreage of Wisconsin) were thinned and injured to a degree as to be no longer of practical value for hay. Most of such losses developed in areas where ice formed and persisted for 20 days or more in direct contact with the soil surface and the exposed parts of the crowns of alfalfa. Losses were much lower where the ice crust was porous and where a layer of snow prevailed between the ice sheet and the soil. In February, 1922, a similar but less extensive sheet of ice in this same general area resulted in the loss of 40,000 acres of alfalfa which constituted about one-fourth of the total acreage of the state at that time.

REVIEW OF LITERATURE

Although ice sheets may be serious factors in the winter survival of alfalfa and other over-wintering crops, little work has been done to ascertain the causal aspects of such injury. A recent monograph by Levitt (6) gives a critical review of the literature on frost killing and hardiness, and the well-known bibliography of low temperature relations of plants by Harvey is very inclusive. The authors, however, have found very little literature pertaining to the fundamental factors involved in ice-sheet killing.

Bugaevskii and Zitnikova (2) mentioned ice as a cause of killing in 1936 when they reported death of wheat plants after 54 days beneath an ice crust and suggested a lack of oxygen as the factor involved. Brierley, *et al.* (1) coated dormant strawberry plants with clear ice and noted internal carbon dioxide increases up to 24% and oxygen decreases to as low as 4% during three weeks at tempera-

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[3]Figures in parenthesis refer to "Literature Cited", p. 893.

tures of -1° to -6° C. However, they attributed the greater share of winterkilling from ice contacts in the field to properties of greater thermal conductivity which would make the effects of low temperature more pronounced.

Sprague and Graber (7) began studies on the causal aspects of ice-sheet injury of alfalfa in 1933. They observed that the formation of ice in contact with the roots and crowns of hardy alfalfa plants was not in itself injurious or lethal, but that the duration of ice contact determined the extent of the injury sustained. Their trials, in which hardened alfalfa roots and crowns were stored in water, ice, and various gaseous media, were designed to determine the effects of the surrounding storage conditions upon survival. Only non-injurious temperatures of storage from 1° to -4°C were used. Pure carbon dioxide in closed test tubes proved to be very injurious as a storage medium. Moreover, carbon dioxide was assumed to accumulate in sufficient quantities as a respiratory product in closed containers of air, water, and other media to reach toxic concentrations contributing to the observed injury. When plants were stored in atmospheres designed to remove excess carbon dioxide or to prevent its accumulation, such as flowing air, flowing nitrogen, and air bubbled through water, they suffered much less injury than plants confined for similar periods in ice, still water, still nitrogen, still carbon dioxide, flowing carbon dioxide, and carbon dioxide bubbled through water. With the exception of those stored in solid cakes of ice, cold-hardened alfalfa plants maintained in a water medium through which carbon dioxide was bubbled suffered the most rapid and intense injury of those in any of the storage media employed. Plants stored in closed containers of still nitrogen were injured somewhat more severely than in still air and oxygen deficiencies were regarded as being associated with the accumulations of the products of anaerobic respiration.

The injurious effect of carbon dioxide as an external medium is not a recent observation. As early as 1804, Saussure, cited by Clements (3), observed that growing chestnut plants, whose roots were stored in carbon dioxide, died in 7 to 8 days, while those stored in air were still vigorous at the end of three weeks. Corenwinder, also cited by Clements (3), found that marsh plants died quickly when their roots were submerged in water charged with carbon dioxide. Free (4) observed the same relation in buckwheat.

EXPERIMENTAL WORK

The investigations reported in this paper were begun in October, 1936, and are a continuation of the studies begun by Sprague and Graber (7) in 1933. Some of the previous trials were repeated and additional experiments were designed to determine further the role of carbon dioxide and other factors thought to be immediately associated with ice-sheet injury to alfalfa.

All trials were conducted in the laboratory with seedling plants of alfalfa grown in the field, and in most instances they were cold hardened there. The temperature chamber consisted of an ammonia-cooled box regulated to provide temperatures not lower than -4° C. A 25-gallon water bath built into one end of the cold box and cooled by a freezing unit from the ammonia system was held at 1° C. Subsequent to storage treatment, the samples of dormant alfalfa plants from the cold box were submerged in the cold water bath during the time necessary for slow thawing, after which all samples were removed to the greenhouse and transplanted in quartz sand. The dry weight of top growth produced during a period of 3 weeks under continuous illumination was used as the index of the injury

inflicted during the preceding storage period. The selection of quartz sand, in preference to soil, in which to transplant and observe growth was considered more advantageous from the standpoint of providing more uniform growing conditions and relying entirely upon the resources of the treated plant for growth recovery.

RESULTS

SURVIVAL AS INFLUENCED BY STORAGE MEDIA (EXPERIMENT I)

On October 12, 1936, healthy 1-year-old Turkestan alfalfa plants were brought into the laboratory from the field and, after a hurried washing in cold tap water, were wrapped in moist towels and stored in the cold box at 5° C. On October 20, they were removed and trimmed to a length of 5 cm from the cotyledonary region upward and 10 cm from the same region downward. Selecting the plants as nearly as possible for uniformity of root and crown, 20 samples were sorted out, each composed of 10 plants. Five of the samples were placed in quart-size ice cream containers and frozen in solid blocks of ice. Five more were placed in tightly sealed 80 cc pyrex test tubes with air as the surrounding medium. Each of the 10 remaining samples was placed in a 980-cc glass jar filled with tap water. Five of these jars were fitted with rubber stoppers, care being taken to expel all of the air possible when inserting the stopper. The remaining five were provided with delivery tubes and, by means of a series arrangement, precooled tap water was circulated over the roots at a rate of 60 cc per minute. The samples in still or flowing water were placed in the water bath at 1° C; those in ice and still air were placed in the cold box at -3° C. Samples were removed from storage at successive intervals of 10 days during a 60-day period. Those stored in ice were thawed for 8 hours in air at 1° C, after which all of the samples were transplanted in the greenhouse for a 3-week period of growth.

The oven-dried weights of top growth produced during 3 weeks in the greenhouse (Table 1) by each of the samples of 10 plants were used as a basis for determining the degree of injury from previous storage in various media. Since light, temperature, and other growth factors varied from one period to another, the dry weight data, as

TABLE 1.—*Grams of oven-dry top growth produced in the greenhouse by young alfalfa plants following periods of storage in water, air, and ice.**

Days of storage	Running water		Still water		Still air		Ice	
	Dry weight, grams	Recovery, %	Dry weight, grams	Recovery, %	Dry weight, grams	Recovery, %	Dry weight, grams	Recovery, %
10	4.88	100	2.48	50.8	2.92	59.8	0.59	12.0
20	4.55	100	2.92	64.1	1.82	40.0	0.00	0.0
30	7.13	100	0.72	10.1	1.97	27.6	0.00	0.0
40	6.23	100	0.72	11.6	2.02	32.4	0.00	0.0
60	4.57	100	0.00	0.0	0.02	0.5	0.00	0.0

*Experiment I, series of October 20 to December 19, 1936. Storage in water was at 1° C and in air and ice at -3° C.

such, do not give an adequate comparison for the effects of the various storage treatments. Consequently, the percentage of recovery is calculated on the basis of 100 for all samples stored in circulating water which had a complete survival for all periods of storage and later made a vigorous growth.

The alfalfa plants used in this trial were but partially cold-hardened as taken from the field. Those stored in blocks of ice were first to show severe injury and were the only ones where the loss in survival was 100% with a storage period of 20 days. They were followed in order by the injury sustained by samples stored in still water and still air. The samples surrounded by a constant flow of water showed no evidence of injury during the entire period of 60 days of storage. These data support the hypothesis that waste products produced during dormancy are carried off adequately by flowing water to prevent injury; whereas, when plants are confined in closed containers of water, such respiratory products eventually reach toxic concentrations. The injuries sustained from storage in still air were less than those in still water even though the samples of alfalfa plants were confined in 80-cc test tubes of air as compared with 980-cc jars for the plants stored in water. With alfalfa plants frozen in blocks of ice, the opportunity for the diffusion and removal of waste products was extremely small and apparently their internal accumulations and pressures were determining factors resulting in the death of all plants during 20 days of such storage.

EFFECT OF STORAGE IN CLOSED CONTAINERS OF VARIOUS SIZES (EXPERIMENT II)

On November 12, 1938, after several hard frosts, several thousand plants of Grimm alfalfa 3½ months of age were dug from the field, selected for uniformity, "heeled in" in the field in bunches of about 250, and covered with straw. This provided a convenient supply of hardened plant material throughout the winter season. On December 17 about 500 of the hardened plants were brought into the laboratory, washed, trimmed to root lengths of 10 cm and crown lengths of 5 cm, as in experiment 1, and grouped into uniform samples of eight plants each. In this experiment 10 samples were stored in large-mouth jars of approximately 980 cc capacity and 10 more were stored in test tubes of 80 cc capacity. Five of the test tubes and five of the jars were filled with tap water, tightly fitted with solid rubber stoppers, and placed in the water bath for storage at 1° C. The remaining five jars and five tubes were tightly stoppered with air as the surrounding medium and were stored in the cold box at −3° C. The measurements of recovery in the greenhouse, made as before, are presented in Table 2.

Whether in air or water, plants confined in large jars survived storage much longer and were more vigorous following any single storage period than were plants confined to the test tubes of much smaller capacity. Water was more detrimental as a storage medium than air.

Respiratory products of the alfalfa, associated microorganisms, or both, accumulated in one of the test tubes containing still water

to the extent that sufficient pressure was developed to blow out the stopper. The stoppers of the remaining tubes were promptly wired into place to prevent further loss, but upon opening them at a later date the sudden release of pressure induced a noticeable amount of effervescence. That the escaping gas consisted primarily of carbon dioxide was verified by precipitation with barium hydro-oxide. The exact amounts were not determined, but it was observed that large quantities of gaseous by-products of respiration had been released by the dormant plants stored at 1° C. Assuming the respiration of replicate plant samples to be nearly equal, the respiratory products would be expected to reach higher concentrations more quickly in the small tubes than in the larger jars.

TABLE 2.—*Grams of oven-dry top growth produced by hardy Grimm alfalfa plants during 3 weeks in the greenhouse following storage in closed large and small containers of water and air at 1° C and −3° C, respectively.**

Days of storage	Storage in water at 1° C		Storage in air at −3° C	
	Test tubes (80 cc)	Jars (980 cc)	Test tubes (80 cc)	Jars (980 cc)
0	1.24	1.24	1.24	1.24
15	1.58	—	—	—
20	1.15	2.31	—	—
25	0.24	—	—	—
30	0.00	0.72	—	—
32	—	—	0.03	0.42
36	—	0.56	—	—
40	—	—	0.00	1.10
46	—	0.00	0.00	0.10
61	—	0.00	0.00	0.44
75	—	—	0.00	0.00

*Experiment II, series of December 19, 1938 to March 5, 1939.

CARBON DIOXIDE PRODUCTION DURING STORAGE (EXPERIMENT III)

The plants used in experiment III were taken from the same field which provided the plant material for experiment II. They were removed from the field on April 25, 1939, just as the spring growth was beginning to be evident. After 4 days in the cold box at 2° C, 12 samples of 10 plants each were placed in 12 33×300 mm test tubes, 6 of which were filled with nitrogen and 6 with air as the surrounding media. Each tube was provided with a two-hole rubber stopper and delivery tubes, to the exposed ends of which were attached rubber unions and screw pinch clamps. Storage in still air and still nitrogen was in the cold box at −3° C and removal from storage was at weekly intervals. After thawing for several hours at 1° C, each closed tube in turn was fitted into a modified respiratory apparatus and carbon dioxide-free air was passed over the roots until the accumulated carbon dioxide was removed and determined quantitatively. The calculated concentrations of carbon dioxide in grams per liter of surrounding storage media and the oven-dry weights of top growth produced by each sample during 3 weeks growth in the greenhouse are presented in Table 3.

TABLE 3.—*Growth recovery and concentrations of accumulated carbon dioxide from alfalfa plants previously stored for 0 to 35 days at -3° C in nitrogen and in air.**

Days of storage	Storage in air		Storage in nitrogen	
	Dry weight of top growth, grams	Conc. of CO_2, grams per liter	Dry weight of top growth, grams	Conc. of CO_2, grams per liter
0	1.58	0.0422	1.58	0.0422
7	0.74	0.2578	0.63	0.1822
10	1.16	0.2335	0.92	0.1835
14	1.34	0.3622	0.63	0.2187
21	0.44	0.4956	0.24	—
28	trace	0.3609	trace	0.2483
35	0.08	0.3817	0.11	0.5217

*Experiment III, series of April 29 to June 2, 1939.

In atmospheres of both air and nitrogen little injury was inflicted upon stored plants during the first 14 days. The concentration of carbon dioxide surrounding the roots increased with the duration of the storage period and there was a corresponding increase in the injury sustained by the plants (Fig. 1). After storage all of the samples were observed to have liberated in excess of 100 mg of carbon dioxide, indicating that even at -3° C considerable activity occurs. The presence of oxygen in the tubes containing air appeared to permit a more rapid respiratory rate as indicated by the greater carbon dioxide liberations. However, injury was experienced sooner by plants stored in nitrogen, though the amounts of carbon dioxide produced were considerably less than those produced by the plants stored in air. This suggests that the products of anaerobic respiration may have been very toxic.

EFFECT OF CARBON DIOXIDE CONCENTRATION UPON SURVIVAL (EXPERIMENT IV)

Early in June, 1939, nonhardened Grimm alfalfa plants were obtained from the same field which provided material for experiments II and III. They were washed and trimmed as before, wrapped in wet towels, and placed in the cold box at 2° C for 12 days. At the end of that time 25 samples of 10 plants each were selected and placed into 25 33×300 mm pyrex test tubes. Five series of five tubes each were provided with delivery tubes and rubber unions and arranged in a series. Each of the five series was provided with one of five concentrations of carbon dioxide in flowing air as follows: 50%, 25%, 10%, and 5% carbon dioxide in air by weight and carbon dioxide-free air. The carbon dioxide-free air was prepared in the laboratory by passing air from the laboratory jet over soda lime and bubbling through barium hydroxide. The other four media were mixed in gas cylinders at 100 atmospheres of pressure from commercial supplies. The flow of gas was regulated in each case to from 5 to 6 bubbles per second and all samples were placed in

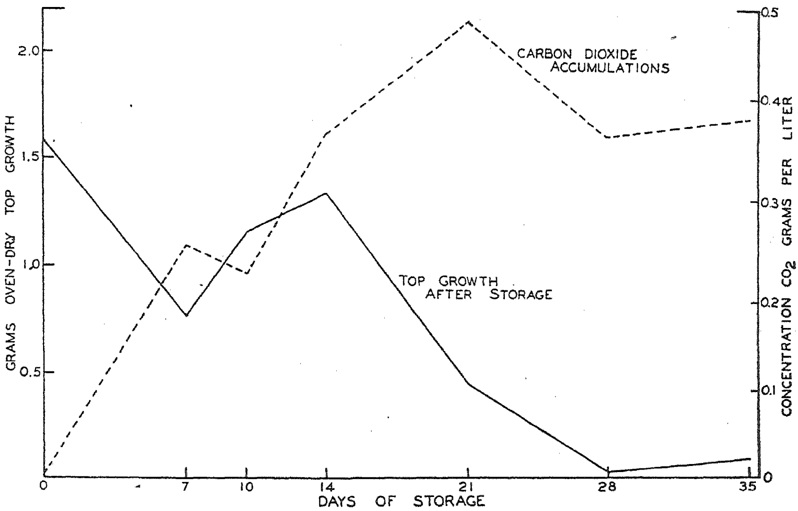

FIG. 1.—Top growth after storage and accumulations of carbon dioxide from 10 samples of Grimm alfalfa plants stored in test tubes with air as a surrounding medium. Temperature during storage was maintained at −3° C. Experiment III, series of April 29 to June 2, 1939.

the cold box at 1° C. At several intervals of storage, samples from each series were transferred to favorable conditions for growth in the greenhouse.

The weights of oven-dry top growth produced during the recovery period are presented in Table 4. Plants stored in atmospheres of 10%, 5%, and 0% carbon dioxide survived 35 days of storage very well and were only moderately weakened after 54 days of storage. Samples surrounded by 25% and 50% carbon dioxide were seriously weakened after 21 days and were dead after 54 days of storage. Plants pictured in Fig. 2 show the manner and extent of recovery following the storage conditions of this experiment.

In this experiment known concentrations of carbon dioxide were provided in flowing atmospheres. The injury inflicted during storage

TABLE 4.—*Growth recovery of 10 plant samples of Grimm alfalfa stored for 0 to 54 days in various concentrations of carbon dioxide in flowing air at 1° C.**

Days of storage	Grams of oven-dry top growth produced by 10 plants stored in				
	50% CO_2	25% CO_2	10% CO_2	5% CO_2	CO_2-free
0	2.15	2.15	2.15	2.15	2.15
11	1.60	1.69	1.78	1.34	1.04
21	0.65	0.72	2.01	2.08	1.52
27	0.18	0.30	2.66	1.27	1.54
35	0.13	0.45	1.16	1.27	1.09
54	0.00	0.00	0.71	0.92	0.70

*Experiment IV, series of June 17 to August 11, 1939.

clearly indicates the detrimental effects of high concentrations of carbon dioxide. The data indicate (Table 4), however, that carbon

FIG. 2.—Relative growth of Grimm alfalfa plants during 3 weeks in the greenhouse following 35 days (A) and 54 days (B) of storage. From left to right are pictured samples stored in 50%, 25%, 10%, 5%, and 0% carbon dioxide in flowing air. Temperature during storage was maintained at 1° C. Experiment IV, series of June 17, to August 10, 1939.

dioxide is not lethal unless external concentrations are maintained for a considerable length of time. Plants surrounded by air containing 50% carbon dioxide required 3 weeks to show severe weakening rather than a few days or hours as might be expected if the gas itself were directly toxic. This suggests that high external concentrations of carbon dioxide may favor the production of compounds in the plant tissue which are directly toxic.

The plants stored in the carbon dioxide-free medium were injured more severely than those stored in either 5% or 10% mixtures of the gas, but were not injured nearly as much as those samples stored in 25% or 50% mixtures. Further evidence of the injuries from storage in carbon dioxide-free air was observed in experiment V.

EFFECTS OF THE PRESENCE AND ABSENCE OF CO_2 AND O_2 (EXPERIMENT V)

On January 4, 1940, 380 hardened Grimm alfalfa plants 5 months of age were brought into the laboratory and arranged into 38 samples of 10 plants each. Twenty of these samples were placed in large pyrex test tubes fitted with one-hole rubber stoppers into which were fitted glass stopcocks. The stopcocks were opened daily during storage just long enough to release any pressure which might have developed but not sufficiently to allow any appreciable gaseous exchange. A small vial of 5% potassium hydroxide was placed in the bottom of each of five of the test tubes to remove the CO_2 from the surrounding atmosphere whether originally contained in the medium or later liberated by the plants as a product of respiration. Oxygen was present in these tubes ($-CO_2+O_2$) as a component of the air. Five more tubes ($+CO_2$ $-O_2$) were filled with an atmosphere from which the oxygen had been removed and in which carbon dioxide was allowed to accumulate during storage. The atmospheres within another five tubes were kept devoid of both carbon dioxide and oxygen ($-CO_2-O_2$) throughout the storage period by inserting a small vial of potassium pyrogallate into each tube. The remaining five tubes ($+CO_2+O_2$) were provided with air as the surrounding medium and carbon dioxide was allowed to accumulate as a product of respiration. In addition, five samples were frozen in solid blocks of ice, five more were wrapped loosely in wet towels, and five were placed in stoppered and sealed test tubes of air ($+CO_2+O_2$). All samples were placed in the cold box at $-4°$ C. Three untreated (check) samples were immediately transplanted in sand for growth in the greenhouse. Samples from each series under treatment were removed from the cold box at intervals of about 5 days, allowed to thaw several hours at 1° to 2° C and were then planted in the greenhouse.

Oven-dry weights of the top growth produced by the samples during 3 weeks in the greenhouse, including the check samples not stored, are presented in Table 5 as measures of the injury inflicted during storage. In this experiment, storage periods were considerably shortened from those of previous experiments and atmospheric pressures were maintained in most instances. The plant material used was high in reserves and in cold hardiness and in some cases survival was

TABLE 5.—*Oven-dry top growth produced by Grimm alfalfa during 3 weeks in the greenhouse after storage in test tubes containing various media for periods of 0 to 32 days at -4° C.**

Days of storage	Grams of oven-dry top growth produced following storage in						
	Atmospheric pressure					Increased pressure	
	Open-air check	$+CO_2-O_2$	$-CO_2+O_2$	$-CO_2-O_2$	$+CO_2+O_2$	$+CO_2+O_2$	Ice
0	1.82	1.82	1.82	1.82	1.82	1.82	1.82
7	—	—	—	—	—	—	1.97
10	1.08	2.26	1.68	2.19	1.75	1.85	—
12	—	—	—	—	—	—	1.57
15	1.50	1.00	2.88	1.46	1.68	0.86	—
20	1.87	2.74	1.53	1.60	2.49	1.45	—
26	1.76	1.56	1.27	0.54	1.68	0.75	0.00
32	1.82	1.60	1.17	0.00	1.55	0.71	0.00

*Experiment V, series of January 6 to February 7, 1940.

considerably higher than in comparable treatments previously reported.

Samples frozen in solid cakes of ice were damaged slightly up to 12 days but were dead following 26 days in the sealed condition, while plants wrapped in wet towels showed no evidence of injury throughout 32 days of storage. With high pressures and concentrations of carbon dioxide developing during storage in ice, the resultant injuries, as might be expected, were much more intense than those which occurred in sealed test tubes of air. Plants stored in atmospheres devoid of either carbon dioxide or oxygen were injured very little throughout the duration of the experiment, with the exception of the unaccountably low value obtained with 15 days of storage without oxygen ($+CO_2-O_2$). However, those plants surrounded by an atmosphere kept devoid of both carbon dioxide and oxygen were severely weakened at 26 days and death had ensued with 32 days of storage even though pressures were normal. With both oxygen and carbon dioxide lacking in the storage medium the severity of the injuries sustained was similar to that of the alfalfa plants sealed in solid blocks of ice. Weights of all samples, determined before and after storage, make it unlikely that the observed killing was due to desiccation through the use of the concentrated and noncontacting absorbing agents. It is suggested that the duration of the respiratory activities of dormant alfalfa plants may be conditioned by the presence of carbon dioxide in an atmosphere devoid of oxygen.

The series of alfalfa samples surrounded by air maintained at atmospheric pressure ($+CO_2+O_2$) suffered no injurious effects (Table 5, column 6), while plants in sealed tubes of air ($+CO_2+O_2$) in which more than atmospheric pressures developed were severely

weakened (Table 5, column 7) after 12 days of storage. Plants of a previous experiment incorporating similar treatments are pictured in Fig. 3.

Close observation of plants after being frozen in solid blocks of ice and stored for from 4 to 5 weeks revealed that the ice in direct contact with the root and crown was the first to melt when exposed to thawing temperatures. As the seal was broken, numerous gas bubbles were observed to escape from the tissue as though they had been

FIG. 3.—Three weeks' recovery of Grimm alfalfa following 40 days of storage at $-4°$ C in (left to right) ice, stoppered tubes of air, tubes of air stoppered to allow for carbon dioxide accumulations but at atmospheric pressure, and check (wrapped in wet towels). Experiment V, series of October 29 to December 7, 1939.

confined under considerable pressure. A drop of barium hydroxide applied to the point of exit produced a white precipitate, indicating that carbon dioxide was present. Increased carbon dioxide pressure during storage would tend to hold more of the carbon dioxide and other by-products in the tissues. Survival was very much improved in experiment II where a larger space was provided around the plants during storage. It would appear that the injury from ice sheets is amplified very considerably by a confined and tightly sealed condi-

tion of the plants. With respiration progressing at the rate suggested in experiment III, pressures considerably higher than atmospheric would be expected within a relatvely short time with alfalfa plants sealed in small containers or especially when frozen in solid blocks of ice.

DISCUSSION

Ice sheet damage of alfalfa in the field is generally characterized by its totality in that nearly all plants are killed. Differential injury rarely occurs between hardy and less hardy varieties but observations indicate that young, well-established new seedings of hardy varieties of alfalfa are more resistant than older stands of the same varieties. Under field conditions where numerous factors are usually associated with winter injury, it is possible that ice sheets may cause death directly from cold. Ice has a thermal conductivity four times as great as water and about 100 times that of air. It would seem, therefore, that a contacting sheet of ice would provide a much lower degree of insulation than that of air partially entrapped by stubble and other surface residues in the field. The fact, however, that differentials in ice sheet injury between hardy and less hardy varieties are not of common occurrence would indicate that cold is not the dominant factor in ice-sheet damage. Many other field observations support the belief that injury is usually the result of the sealing effect of contacting and enduring formations of ice. For example, alfalfa stands are frequently damaged by late fall or winter applications of coarse lumpy manure. Field studies of such losses have shown that where injury occurred, ice had formed beneath the larger clumps of manure and remained there long after all the snow on the field had melted. It would seem that the manure had insulated the plants (and also the ice), but the contacting ice persisted sufficiently to cause toxic accumulations and pressures of carbon dioxide from the crowns. Similar situations have resulted from ice formation beneath loose bunches of hay remaining in the field and also under the heavy accumulations of top growth from productive stands of alfalfa which were not cut or grazed during the previous growing season. In such instances the plants are well insulated, but the ice formations which are often induced by such excessive vegetative cover persist and become lethal. It is known that cattle in snow-covered fields are not likely to be harmful to stands of alfalfa if the snow is dry and not of such a consistency to be converted to ice by tramping. Such field evidences, while not conclusive, are indicative.

In the trials reported in this paper where the simple effect of cold injury was eliminated, the evidence appears to be quite conclusive that ice injury occurred as a result of the inadequate diffusion of carbon dioxide which, with increasing concentrations and pressures, developed a toxic condition in the plant. More direct measurements of the occurrence of organic acids and other compounds occurring in the tissues during storage in various media are needed to interpret the injury sustained by alfalfa plants.

Determinations of acidity and its possible effect upon the enzymatic activities offer another opportunity to ascertain more speci-

fically the factors involved in toxicity resulting from respiration during storage in various media.

SUMMARY

The dry weight of top growth produced by transplanted alfalfa during 3 weeks in a greenhouse was used as a measure of the injury sustained from previous periods of storage of dormant plants in various media at harmless temperatures near freezing. The media included still and flowing air, still and flowing water, nitrogen, various concentrations of carbon-dioxide in flowing air, contacting ice, and of carbon-dioxide and oxygen in various ratios and at different pressures.

Dormant, cold-hardened plants frozen and maintained in blocks of ice were weakened after 12 days and all were dead with 20 to 26 days of such storage. Contacting ice was the most injurious of all the storage treatments employed. Circulating water allowed complete survival and vigorous growth after 60 days of storage, while plants confined in still water were weakened after 30 days and all were dead after 60 days at 1° C. Storage in still water was more injurious than storage in still air. Confinement in large containers of either water or air was more conducive to good survival and vigorous growth after any period of storage than confinement in small containers. Storage at pressures higher than atmospheric, resulting from respiration in closed containers, was much more injurious than storage at normal pressures. Measurements of carbon dioxide liberated by dormant alfalfa plants stored in closed test tubes of air or of nitrogen showed a direct relationship between the developing concentrations of the gas and the injury sustained. Although more carbon dioxide was liberated in air than in nitrogen, the injury resulting with the former was usually slightly less, indicating that the products of anaerobic respiration are injurious.

Circulating atmospheres of 25% or 50% carbon dioxide in air produced some weakening at 21, 27, and 35 days and were lethal at 54 days, while plants stored in 0, 5%, and 10% mixtures all showed fair survival and growth after 54 days of storage. Even at the highest concentration a duration of the storage period was required for killing which indicates that external accumulations of carbon dioxide are not directly toxic but that a duration of exposure to the gas may cause internal concentrations of respiratory compounds which are toxic to the cells.

Storage for 32 days in either a carbon dioxide-free or oxygen-free atmosphere provided by absorbing agents was found to be slightly injurious to dormant alfalfa plants, but an intensity of injury similar to that of storage in solid blocks of ice occurred when both carbon dioxide and oxygen were removed by absorption. This suggests that some carbon dioxide was essential for prolonging the respiratory activities of dormant alfalfa plants in the absence of oxygen.

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EFFECT OF MANGANESE ON THE MICROFLORA AND RESPIRATION OF SOME OREGON SOILS[1]

ALBERT W. MARSH AND WALTER B. BOLLEN[2]

BENEFICIAL effects resulting from the addition of manganese to soils have been in part attributed to its stimulation of the soil microorganisms. These microorganisms in turn create a better root environment, release additional mineral nutrients, and promote increased crop yields. Brown and Minges (2)[3] state that $MnSO_4$ at 100 pounds per acre appreciably increased both ammonification and nitrification. Ammonification but not nitrification may be increased at considerably higher rates. They conclude that, "if a crop responds to moderate applications of $MnSO_4$ or is decreased by larger applications, it may be due to the effect of the manganese on bacterial activity."

Leoncini (6) and Montanari (8) both found that nitrification was increased by small additions of manganese salts.

Deatrich (4) observed that with the addition of manganese, ammonification was stimulated but nitrification reduced.

To investigate these effects further some studies were made on the response of soil microorganisms to added manganese.

SOILS STUDIED

SOILS OF THE WILLAMETTE VALLEY

These soils, developed under a mild, humid climate, receive about 40 inches of rainfall annually. They are acid, noncalcareous soils belonging to the brown earth or gray brown podzolic groups.

1. *Chehalis silty clay loam.*—This is a young, moderately heavy, friable, alluvial soil deposited from still water during flood stages. It is a brown earth, very little leached, and is slightly acid in reaction. It possesses good external and internal drainage.

2. *Willamette silty clay loam.*—A mature soil, moderately heavy over a compact subsoil, weathered from old valley fill parent material of basaltic origin. This soil has good external drainage and is moderately acid.

3. *Newberg loamy sand.*—This soil is a brown to light brown, coarse-textured alluvial soil deposited in billows and waves by rapidly moving water. It is frequently subject to overflow, has excessive internal drainage, slightly acid reaction, and low organic matter content.

4. *Melbourne clay loam.*—An upland brown to yellowish brown, moderately heavy residual soil developed on sandstone and shale. It has a moderate supply of organic matter, good moisture retention, and is moderately acid.

5. *Dayton silty clay loam.*—This is a gray to drab, heavy-textured soil. It is developed on the level portions of the valley floor where drainage is poor, the

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[3]Figures in parenthesis refer to "Literature Cited", p. 899.

subsoil is compact and slowly pervious. Because of this it is water logged during a large portion of the year, producing anaerobic conditions and mottling.

PEAT SOILS

1. *Braillier peat.*—This is a coarse, woody, sphagnum peat soil of brown color formed in the marshes of the lower Columbia River Valley. This peat is only slightly decomposed, low in minerals, and strongly leached. It has a pH of 4.1.

2. *Clatskanie peat.*—This is a partially decomposed, grayish brown peat soil of rather high mineral content. It is formed in the Columbia River Valley, subject to periodic overflow and silting. It has a pH of 4.8.

3. *Klamath peat.*—This soil is a well-decomposed tule-sedge peat formed under semi-arid conditions east of the Cascade Mountains. It is almost black in color, has a slightly basic reaction, pH 7.7, and is well supplied with soluble salts.[4]

INFLUENCE OF MANGANESE ON MICROBIAL POPULATION

Samples of the above soils, except Klamath peat which was sent in as a sacked bulk sample, were collected in sterile bottles and brought to the laboratory. They were screened with aseptic precautions, samples weighed out and placed in sterile jars, six for each soil type. Two served as checks, two received $MnSO_4$ in solution at the rate of 40 pounds (equivalent to 15 pounds of Mn) per acre, and two received $MnSO_4$ at 100 pounds (equivalent to 36 pounds of Mn) per acre.[5] Sufficient sterile distilled water was added to bring the soil up to 60% of its saturation capacity and the jars placed in the incubator at 28° C.

After 5 days one jar of each treatment was removed from the incubator and sufficient sterile water added to make a 1:5 extract. This was well shaken and plated out in duplicate, using appropriate dilutions. Peptone-glucose-acid agar was used in the lower dilutions for molds and sodium-albuminate agar on the higher dilutions for bacteria and *Actinomyces*. All plates were incubated at 28° C. Molds were counted and differentiated after 4 days, the bacteria and *Actinomyces* after 10 days. The remaining jars were incubated 30 days, then removed and the counting procedure carried out as previously described.

The results are not presented in detail since noteworthy differences were found in only a few instances. Significant changes resulted from manganese sulfate treatment in the following cases: The 40-pound rate of application doubled the number of molds in Willamette silty clay loam soil in 5 days without appreciably altering the differential count; the effect was still evident though less pronounced at 30 days. The effect produced by the 100-pound treatment was similar but less pronounced, and at 30 days had disappeared. Molds were definitely decreased in Newberg loamy sand by the additions, especially after 30 days. Both the 40- and 100-pound treatments

[4]Pot and field trials with some of these soils have indicated that increased crop yields result from the application of manganese to the Klamath peat and Braillier peat.

[5]Calculated on the basis of peat soils at 1,000,000 pounds and mineral soils at 2,000,000 pounds per acre.

practically doubled the bacteria and *Actinomyces* in Chehalis silty clay loam at 5 days; at 30 days the bacteria had increased 20 fold, largely at the expense of *Actinomyces*. In Brallier peat soil manganese additions increased both molds and bacteria without appreciably altering the differential count ratios; the 40-pound rate was the more effective and the influence was most pronounced at 5 days.

INFLUENCE OF MANGANESE ON SOIL RESPIRATION

Since the foregoing results appeared inconclusive, it was deemed desirable to carry out a more comprehensive experiment on a few soils of widely different manganese content. If manganese exerts an appreciable effect on the microorganisms of the soil, the effect should be directly reflected in assimilative activities as measured by respiration or CO_2 evolution. Therefore, a respiration study was carried out with the three following soils: Klamath peat soil, which is low in manganese; Chehalis silty clay loam, which is high in manganese; and Newberg loamy sand, which is intermediate in manganese.

Microbial analyses of the soils at the beginning of respiration were made as described in the previous section, and the results are given in Table 1. The 1:5 water extract was also analyzed for nitrate by the phenoldisulfonic acid colorimetric method of Harper (5), for sulfate by the turbidity method of Schreiner and Failyer (9), and for phosphate by Truog and Meyer's modification of the Deniges method (10). The pH was determined by the Coleman glass electrode. Total nitrogen was determined by the Kjeldahl method and total carbon by dry combustion in an electric furnace. Manganese was determined on the water and ammonium acetate extracts by the method of Willard and Greathouse (11). Results of chemical analyses are shown in Table 2.

Respiration measurements were obtained as described by Bollen (1), using 500 grams of mineral soil and 250 grams of peat soil in quart milk bottles. Eight samples of each soil were placed in the bottles, four serving as checks and four receiving $MnSO_4$ in solution equivalent to 100 pounds per acre. Water to give 60% saturation

TABLE 1.—*Microbial analysis of original soil samples used in respiration experiment.*

Soil	Moisture, %*	Molds				Bacteria	
		Thousands per gram of soil†	Mucors, %	Aspergilli, %	Penicillia, %	Millions per gram of soil†	Actinomyces, %
Klamath peat	115.0	62.5	2.4	1.6	45.6	77.0	24.7
Chehalis silty clay loam..	34.7	21.3	11.8	0.0	23.5	8.9	15.8
Newberg loamy sand	27.8	21.3	10.6	2.3	36.5	7.9	15.2

*60% of saturation capacity.
†Water-free basis.

TABLE 2.—*Chemical analysis of original soil samples.**

Soil	pH	N as NO_3, p.p.m.	S as SO_4, p.p.m.	P as PO_4, p.p.m.	Total N, %	Total C, %	C:N	Mn, p.p.m.†
Klamath..	7.7	65.3	43.0	1.08	1.13	11.60	10.27	15.2
Chehalis..	6.8	1.0	6.1	0.46	0.21	2.14	10.25	158.3
Newberg..	6.4	1.9	1.0	0.42	0.07	0.85	12.92	93.2

*Data expressed on water-free basis.
†This is the sum of the water-soluble Mn, exchangeable Mn, and easily reducible MnO_2, obtained by successive extractions with H_2O, neutral normal ammonium acetate, and neutral normal ammonium acetate containing 0.2% hydroquinone.

was added to all soils. Two of each treatment were placed on the pressure line for measurement of CO_2 evolution. Duplicates were autoclaved for 3½ hours. After cooling, these were attached to the pressure line with cotton plug protection against contamination.

The CO_2 evolved was bubbled through normal NaOH in 50-ml test tubes, which were replaced each day at first, later at longer intervals. The absorbed CO_2 was determined by double titration, using thymol-blue and brom-phenol-blue. The aeration was carried on for 55 days. The average CO_2 evolved by each soil expressed as mgms of C per kgm of soil is plotted on Fig. 1.

DISCUSSION

From the results for Klamath peat soil and Newberg loamy sand, it is apparent that manganese stimulates microbial activities with a resulting increase in respiration. The Chehalis silty clay loam soil,

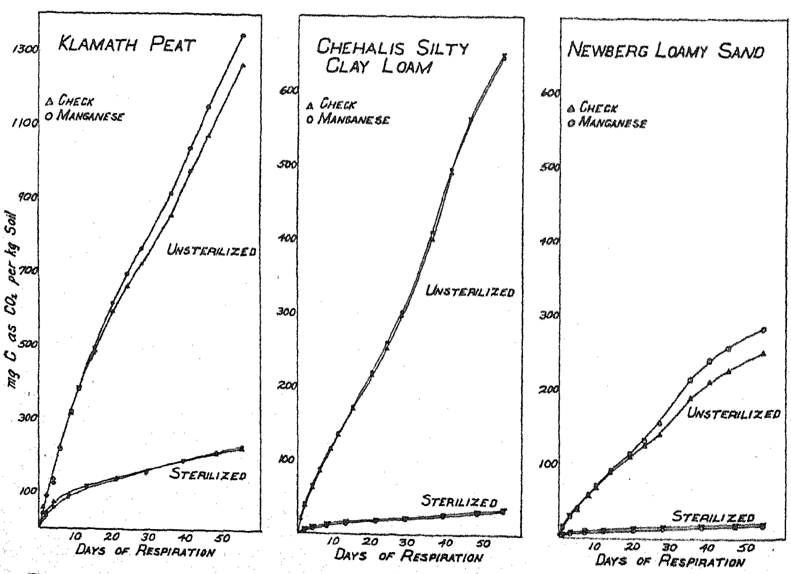

FIG. 1.—The average CO_2 evolved by each soil in mgms of C per kgm of soil.

which has the same C:N ratio as the Klamath peat, did not react similarly. It showed no response to added manganese. Analyses of soil extracts show that the average Chehalis profile contains 150 to 200 p.p.m. of extractable magnanese, already optimum or higher.

Response from added manganese sulfate may be due in part to the sulfate supplied, especially for Willamette Valley soils. That the sulfate had little effect on microbial respiration in the soils studied is evident from the respiration curves. The Klamath peat, which gave the greatest response, contains seven times as much sulfate as the Chehalis silty clay loam, which gave no response. In general, the rate of response was inversely proportional to the content of available manganese (Table 2) and bore no relation to the sulfate content.

Manganese gave no increased CO_2 production in sterilized samples. Steam sterilization, however, according to Conner (3) and McCool (7), releases large amounts of soluble manganese, and this has been confirmed in our greenhouse work.[6] Beans grown on steam-sterilized soil not only produced greater yields but also had three times the manganese content of beans on unsterilized soil. One hundred pounds of manganese sulfate per acre, therefore, could well have little or no beneficial effect when added to a sterilized soil.

While manganese may affect plant growth (a) directly in nutrition of the plant, (b) indirectly through the soil flora, or (c) in both ways, our experiments do not differentiate these effects. The data presented do show a significant effect of manganese on certain microbial functions in certain soils. Under some conditions this may be the primary influence. In general, however, it would seem that increased plant growth due to manganese additions probably results from direct effects.

SUMMARY

Manganese sulfate added to several Oregon soils at rates equivalent to 40- and 100-pounds per acre increased by approximately 100% the mold count in Willamette silty clay loam and Braillier peat, and the bacterial count by 160% in the Braillier peat. It produced a 50% decrease in the mold count in Newberg loamy sand.

The microbial production of CO_2 was increased by manganese sulfate additions at the rate of 100 pounds per acre in the Klamath peat and Newberg soils, but had no apparent effect in the Chehalis silty clay loam. The response was roughly in inverse proportion to available manganese. No effect on nonmicrobial production of CO_2 was apparent.

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EFFECTS OF SINOX, A SELECTIVE WEED SPRAY, ON LEGUME SEEDLINGS, WEEDS, AND CROP YIELDS[1]

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THE chemical sodium dinitro-ortho-cresylate, known commercially as Sinox, has been used in the United States since 1938 for the control of broad-leaved annual weeds in small grain and flax fields. While Sinox has been used primarily for the control of wild mustard, *Brassica arvensis*, it has given excellent control of other annual weeds.

When Sinox was first used in Wisconsin, in 1940, it became evident that more information was needed as to its effects upon legume seedlings associated with nurse crops in weed-infested fields. Westgate and Raynor (3)[3] are apparently the only workers who have reported studies of this problem. They found that seedling alfalfa was too tender to be sprayed with safety, but that when the plants were 6 weeks old and 2 to 4 inches tall they would tolerate a 1:80 dilution of Sinox with water at a rate of 160 gallons per acre.

The direct effects of Sinox on various weeds and the indirect effects on crop plants and yields have been studied in detail by several workers (1, 2, 3). Data on factors influencing effectiveness, cost of applications, equipment needed, and details of recommendations for various crops and weeds are given in these references. In general, the recommended dilutions of Sinox with water vary from 1:80 to 1:120 and rates of application from 80 to 120 gallons of solution per acre.

This paper reports the results of experiments conducted during the 3-year period 1940 to 1942. The primary object of these experiments was to determine the tolerance of seedlings of alfalfa, red clover, and biennial white sweet clover to Sinox. The effects on associated weeds and on crop yields were measured, but since other workers (1, 2, 3) have made more detailed studies along these lines, these phases of the work will not be discussed in detail. The methods and results of each year are presented separately because of differences in experimental methods used in different years. In 1940 the experiments were conducted in Sheboygan and Milwaukee counties and in 1941 and 1942 at the University Hill Farms, Madison, Wis. In all three years a 1% solution of Sinox which contained 2 pounds of ammonium sulfate per 100 gallons of solution was used. According to Robbins, Crafts, and Raynor (2, pages 189–192), ammonium sulfate increases the speed and effectiveness of the killing action such that rain falling 30 to 60 minutes after spraying does not nullify the action of the chemical. Spray pressures used and the temperature and humidity at the time of spraying were not recorded as it has been shown by Westgate and Raynor (3, pages 15–17) that pressures between 75 and 150

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[3]Figures in parenthesis refer to "Literature Cited", p. 908.

pounds per square inch are satisfactory and that only at temperatures below 55°F and at low humidities is the rate and effectiveness of action much reduced.

1940 EXPERIMENTS

METHODS

During 1940, four weed-infested grain fields seeded to legumes were sprayed with Sinox in Milwaukee and Sheboygan counties. In each field several strips were sprayed. Adjacent unsprayed strips were used as controls. All applications were made between May 24 and June 8 when the mustard had from 3 to 7 leaves and the grain was 5 to 8 inches tall. The legume seedlings were 1 to 3 inches tall and had from 4 to 6 leaves. The spray rig used on fields 1, 2, and 3 (Table 1) consisted of a 200-gallon tank mounted on a truck equipped with a pump having a delivery capacity of 15 gallons per minute. The spray boom was 22 feet long and was equipped with nozzles delivering fan-shaped sprays. Field 4 was sprayed with a small, portable two-wheeled rig having a 25-gallon tank and a pump capacity of 1¼ gallons per minute. This rig had a single nozzle which delivered a conical-shaped spray covering an area about 6 feet in diameter.

The weed counts and yields were taken on 1/5,000-acre paired quadrats selected at random on treated and untreated areas. Twenty to 30 paired quadrats were taken on all fields. With the exception of field 2 where counts were made, the legume stands were estimated. All data on legumes and weeds were taken just before grain harvest.

RESULTS

The data in Table 1 give the results obtained during 1940. Sweet clover was very susceptible to the killing action of Sinox. The alfalfa on fields 2 and 3 showed considerable tolerance to Sinox and both of these fields had a good stand of alfalfa on the sprayed areas in the

TABLE 1.—*Effect of 100 gallons of a 1% Sinox solution per acre on legume stands, weeds, and grain yields for four fields in Sheboygan and Milwaukee counties during 1940.*

Field number and location	Nurse crop and legume	Legume stands		Weeds and % control*			Grain yield, bu. per acre	
		Treated	Untreated	WM	WB	LQ	Treated	Untreated
Field 1, Sheboygan County	Barley Sweet clover	Trace	Very good	100	98	—	—†	—†
Field 2, Sheboygan County	Oats Alfalfa	Good	Very good	100	98	98	114.0	100.5
Field 3, Milwaukee County	Barley Alfalfa	Medium	Good	98	98	80	57.6	42.7
Field 4, Milwaukee County	Barley Alfalfa	Trace	Very good	100	98	—	37.0	28.5

*WM = Wild mustard; WB = Wild buckwheat; LQ = Lambsquarter.
†No yield taken.

spring of 1941. The almost complete killing of alfalfa on field 4 was attributed to the use of the small, portable sprayer equipped with a single nozzle. The amount of spray applied could not be accurately controlled, and the rate of application was apparently much in excess of 100 gallons per acre.

In field 2 there was an average of 20 alfalfa plants per square foot on the untreated areas and an average of 12 per square foot on the treated areas. The number of wild mustard plants per square foot in the untreated areas varied from an average of less than 1 for field 1 to 12 for field 3. The percentage control was estimated for weeds other than wild mustard. Wild buckwheat, *Polygonum convolvulus*, which is a very prevalent and troublesome weed in Wisconsin grain fields, was controlled about 98% in all fields. Lambsquarter, *Chenopodium album*, however, was more resistant in field 3. The yield increase on field 2 was not significant, but on fields 3 and 4 the increases were significant at the 1% level.

1941 EXPERIMENTS

METHODS

During 1941, a trial was conducted at the University Hill Farms at Madison, Wis., to determine the effect of a 1% Sinox solution sprayed at rates of 60, 80, and 100 gallons per acre on the stand of sweet clover, red clover, and alfalfa. The effects of these applications on the control of wild mustard, Indian mustard, *Brassica juncea*, and wild turnip, *B. campestris*, and on the stand and yield of flax were also observed. In order to have the plants at different stages of growth when sprayed, seedings were made at three dates, *viz.*, April 28, May 13, and May 24. The design used was a two-way whole plot with three replicates. The individual plots were 22×24 feet. The legumes were seeded at the rate of 12 to 14 pounds per acre and the flax at 3 pecks per acre. Scarified weed seeds were sown at the rate of 200 per square yard on a single square yard area in the center of each individual plot. The spray applications were made on June 18. A stationary pump was located at the side of the field and an 18-foot boom with hose attachment was pulled across the field.

Counts were made on the stands of legumes, weeds, and flax on June 25 and again on the legumes on September 12. Plant counts and yield data were taken on 1/5,000-acre quadrats located in the center of each plot where the weeds had been sown. All weeds in the treated and untreated areas were removed at the time of counting in order to prevent seed setting. The fall counts on legumes were made on identically the same areas as the spring counts.

RESULTS

The data in Table 2 describe the height and stage of plant development at the time of spraying. In Table 3 the effects of the Sinox applications are indicated as the percentage reduction of legume, weed, and flax stands expressed as percentages of the unsprayed checks. The smaller plant counts, especially flax, for the May 13 seeding were the result of dry weather following seeding. It should be noted that sweet clover showed its greatest tolerance to Sinox in the May 13 seeding but was very susceptible in the other seedings.

TABLE 2.—*Stages of development of legume, weed, and flax seedlings when sprayed with Sinox on June 18, 1941.*

Date seeded	Days from seeding to spraying	Height and stage of development		
		Legumes	Weeds	Flax
Apr. 28	51	5–8 inches	16–18 inches; full bloom	14–16 inches; early bloom
May 13	36	4–6 inches	10–12 inches; early bloom	10–12 inches
May 24	25	1–3 inches; 5–8 leaves	2–4 inches; 5–8 leaves	4–6 inches

TABLE 3.—*Effects of a 1% solution of Sinox upon the stands of legumes, weeds, and flax when applied at different rates and stages of growth on June 18, 1941.*

Date of seeding	Gallons of spray per acre	Alfalfa		Red clover		Sweet clover		Wild mustard June 25	Indian mustard June 25	Wild turnip June 25	Flax June 25
		June 25	Sept. 12	June 25	Sept. 12	June 25	Sept. 12				
					Plants per Square Foot						
Apr. 28	0	19	11	13	10	9	3	11	24	16	66
May 13	0	11	9	18	6	8	6	10	12	16	25
May 24	0	21	15	33	15	19	11	15	22	20	62
				Reduction in Stand as Percentage of Check							
Apr. 28	60	4	0	18	0	95	100	0	55	26	5
	80	0	0	14	3	100	100	21	32	21	13
	100	28	27	15	41	100	100	40	51	50	19
May 13	60	0	0	0	0	53	58	11	9	14	22
	80	0	0	10	0	63	73	15	0	16	24
	100	12	0	21	0	91	79	16	27	18	31
May 24	60	49	33	62	76	75	90	80	81	65	20
	80	51	33	66	73	99	100	89	81	81	29
	100	53	49	66	67	99	99	95	95	80	24

Both alfalfa and red clover had developed a high resistance to Sinox at an age of about 5 weeks (Table 3). This resistance as shown for the May 13 seeding was not appreciably reduced for the April 28 seeding. All the legumes seeded May 24 were most susceptible when sprayed about 3½ weeks later. With the exception of sweet clover, however, the number of plants remaining after spraying still provided a good stand. The September counts for the May 24 seeding show a reduction almost twice as great for red clover as for alfalfa. It is believed that since both the seeding and spraying dates were very late, the lower survival of red clover may be attributed

largely to the fact that recovery from spray injury had to occur during the driest portion of the year and, not being as drouth resistant as alfalfa, it showed an abnormal reduction in stand. The various rates of application appear to have had but little effect on the percentage reduction of the legumes.

The best control of weeds was obtained when the spray was applied at an early stage of plant growth. At this time the injury to the legume seedings was also the greatest. It is evident that delaying the time of spraying to 5 or 6 weeks after seeding to allow for the development of resistance to Sinox by the legumes results in very poor weed control. The higher percentage control of weeds for the April 28 seeding as compared with the May 13 seeding is attributed to the more dense stand of flax for the former date. This indicates that weeds are more susceptible to Sinox when the stand of competing plants is good and the weeds more tender.

No information was secured as to how the reduced weed stands might have increased yields, since all weeds were removed shortly after the spray application. However, a measure of the reduction in yield caused by the spray and by the weeds up to the time they were sprayed or removed by hand was secured by taking yields on the sprayed and unsprayed plots each with and without weeds. The yield of flax for the April 28 seeding was reduced approximately 40% by the spray treatment and an additional 40% from weed competition. The flax of this date of seeding was in early bloom when sprayed and was severely burned by the spray. The reduction in yield caused by the weeds in the May 13 seeding up to the time they were removed was about 60% and for the May 24 seeding 15 to 20%. On the areas which had no weeds the average yield reductions for the three rates of Sinox application were 11% for the May 13 seeding and 7% for the May 24 seeding. These figures emphasize the fact that when Sinox is applied at a late stage of growth, flax is severely injured and weed control is poor.

1942 EXPERIMENTS

METHODS

The 1942 experiments were conducted at the University Hill Farms, Madison, Wis., to determine the effect of a 1% Sinox solution sprayed at rates of 60, 80, and 100 gallons per acre on the stands of sweet clover, red clover and alfalfa, on the control of wild mustard and lambsquarter, and on the yield of flax. A split-plot design with four replicates was used. The size of each plot was 3×8 feet. The flax was seeded at 3 pecks per acre over the entire area, and the legumes were seeded at rates of 12 to 14 pounds per acre in randomized strips within each block. Seed of each of the weeds was broadcasted over the entire area at a rate of approximately 10 pounds per acre. All seedings were made on April 22. The spray was applied June 2 and June 9. Small hand sprayers were used which delivered a continuous spray from graduated glass jars. The position of spray treatments was determined at random within each legume strip in each block. The flax was harvested and weed counts made on August 3, 1942. The stand of legumes was determined on September 15 by counting the number of plants found in three square-foot areas taken at random in each plot.

RESULTS

The data in Table 4 give the stages of plant development at each of the two dates of spraying, while those in Table 5 show the effects of the sprayings on the stand of the legumes and weeds and on the yield of flax. It is again evident that sweet clover is very susceptible to Sinox, while red clover and alfalfa show considerable tolerance at rates which give excellent weed control.

TABLE 4.—*Stages of development of legumes, weeds, and flax seeded on April 22 and sprayed at two dates.*

Plant	Sprayed June 2		Sprayed June 9	
	Height, inches	No. true leaves	Height, inches	No. true leaves
Alfalfa	2-4	3-5	4-6	5-8
Red clover	2-3	2-3	3-5	4-5
Sweet clover	2-3	3-5	3-5	4-6
Wild mustard	4-6	4-6	10-18	Early bloom
Lambsquarter	2-3	3-6	4-8	8-12
Flax	6-10	—	10-16	—

TABLE 5.—*Effects of Sinox spray upon the stands of legumes and weeds and upon the yields of flax when applied at three rates and two dates.*

Plant (seeded April 22)	Unsprayed check, No. of plants per sq. ft.	Sprayed June 2, 1942*			Sprayed June 9, 1942*		
		60 gals.	80 gals.	100 gals.	60 gals.	80 gals.	100 gals.
		Reduction of Stand in Percentage of Check					
Alfalfa	54	38	54	54	12	34	22
Red clover	38	7	14	0	7	7	0
Sweet clover	10	95	97	100	91	100	97
Wild mustard	3.2	96	97	99	62	81	66
Lambsquarter	1.8	81	93	95	21	49	33
		Yields in Bushels per Acre†					
Flax	8.6	16.9	15.7	15.2	15.6	16.3	15.2

*1% Sinox at the rate per acre indicated.
†Difference required for significance at the 5% level, 2.4 bushels.

While the tolerance of alfalfa to Sinox increased between June 2 and June 9, it is evident that the poorer weed control would not justify the delay in application. Flax yields were doubled for almost all rates and dates of application. The poorer weed control at the second date of application was not reflected in the flax yields. Apparently this was because the weeds which were not killed were injured so severely that they offered little competition to the flax.

DISCUSSION

An explanation of the relative tolerance of sweet clover, alfalfa, and red clover to Sinox is found in their morphological and develop-

mental characteristics. Examination of spray-injured sweet clover seedlings has shown that nearly all axillary buds fail to develop when most or all of the leaves are killed. This is especially true in very young seedlings or in older plants which are shaded to a considerable extent by the nurse crop or weeds. Sweet clover plants when 5 to 6 weeks old and grown with very little competition, as for the May 13 seeding in Table 3, showed considerable recovery from axillary buds. Buds and leaf primordia of red clover have better protection than those of either alfalfa or sweet clover. This is because red clover has large stipules and practically no internodal elongation in the early developmental stages. Many spray-injured red clover plants with all leaves destroyed and appearing to be entirely dead were observed to send out new leaves within 6 to 8 days after spraying. The basal internodes of alfalfa elongate less than those of sweet clover. This provides alfalfa with more basal axillary buds near the ground than sweet clover. Likewise, alfalfa produces basal adventitious buds while sweet clover does not. The rather fleshy leaves of sweet clover showed signs of injury more rapidly than did the leaves of alfalfa and red clover. This would indicate either a more rapid penetration of the spray into the sweet clover tissue or a greater sensitivity.

The data in Tables 3 and 5 show that in 1941 alfalfa was more tolerant to Sinox than red clover, but that the reverse was true for 1942. A possible explanation of this observation is that in both years the legume with the best stand before treatment showed the greatest percentage reduction from the spray treatment. This indicates a higher percentage survival of the legumes in sparse stands and a lower survival in dense stands.

During 1943 one field seeded to red clover with a very heavy stand of barley was sprayed when the barley was 1 foot high. Observations 1 week after spraying showed normal recovery of the red clover. Extremely dry weather followed, however, and practically 100% of the clover died. Adjacent fields with a less dense nurse crop showed good recovery.

Based upon the actual number of alfalfa plants surviving on the sprayed areas in September of 1941 and 1942, it would seem safe to recommend the use of Sinox on alfalfa seedings infested with weeds. This is in agreement with the results obtained in the 1940 experiments with the exception of one field and with observations made on several commercially sprayed fields in various parts of Wisconsin. The 1942 experimental results and field observations indicate that red clover may be sprayed with as great a degree of safety as alfalfa. There are at least two possible reasons why legumes sprayed at an early stage of growth are more susceptible to injury from Sinox when planted late in the season than when planted early. First, the higher temperatures of late spring and early summer result in the development of more succulent and spray-susceptible seedlings, and second, the moisture and temperature conditions are less favorable for the recovery of the spray-injured plants. The greater susceptibility of weeds to Sinox would make these considerations relatively less important in determining their resistance to this material.

SUMMARY AND CONCLUSIONS

Weed-infested fields and experimental plots seeded to alfalfa, red clover, and sweet clover with nurse crops were sprayed with a 1% solution of Sinox. The rates of application were 60, 80, and 100 gallons per acre applied at several stages of plant growth. The results and conclusions of the experiments conducted in 1940, 1941, and 1942 are summarized as follows:

1. Biennial white sweet clover seedlings were very susceptible to injury by Sinox at all rates of application and showed 60 to 100% reduction in stand when sprayed at all stages of growth.

2. Alfalfa and red clover seedlings were markedly more tolerant to Sinox in all growth stages than were sweet clover seedlings. Alfalfa and red clover developed a high resistance at an age of about 5 to 6 weeks. Up to 4 weeks of age the reduction in stand varied from 0 to 70%. However, a high percentage reduction occurred only where the stand was very dense. In practically all cases where alfalfa and red clover were sprayed a satisfactory stand of these legumes was secured. Extremely dry weather following spraying, however, may result in the failure of legumes to recover satisfactorily.

3. Attempts to reduce the injury to the legume seedlings by delaying the date and reducing the rate of application proved unsatisfactory as this resulted in greater injury to the nurse crop and poorer weed control.

4. The volume of spray applied within the range of 60 to 100 gallons per acre did not appear to be of much importance in determining injury to the legume seedlings.

5. Wild mustard, wild buckwheat, lambsquarter, and other broad-leaved annual weeds were controlled 80 to 100% by spray applications of 80 to 100 gallons per acre of a 1% Sinox solution at a time when the weeds had from three to seven leaves. Less effective control resulted when less than 80 gallons per acre was used or when the weeds were sprayed in more advanced stages of growth.

6. The yields of oats, barley, and flax were increased 10 to 100% by spraying, depending upon the seriousness of the weed infestations and the effectiveness of weed control. Delayed spraying resulted in poor weed control and injury to the grain crop.

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NOTES

EFFECT OF SODIUM ACETATE ON PLANT GROWTH AND SOIL pH VALUE AS INDICATED BY GREENHOUSE EXPERIMENTS

A FERTILIZER material containing sodium acetate as an impurity is being produced as a byproduct of the manufacture of certain war chemicals. In a study of the suitability of this byproduct for agronomic use, experiments were carried out to determine the effect of sodium acetate on the growth of German millet under greenhouse conditions. As a search of the literature revealed no information on the plant-growth effects of sodium acetate, it would seem of interest to record the results of these experiments.

The experiments were made in quadruplicate in 8-inch, bottom-pierced, clay pots, each of which contained 11 pounds of Evesboro loamy sand soil from the Beltsville Research Center, Beltsville, Md. All the pots received a basal application of 0–16–8 fertilizer at the rate of 2,000 pounds per acre (2,000,000 pounds of soil). One series received no nitrogen fertilizer, while the other received nitrogen at the rate of 100 pounds per acre derived equally from ammonium sulfate and sodium nitrate. Crystallized sodium acetate containing 3 molecules of water was applied at rates of 52.5 to 840 pounds per acre. The fertilizer and the sodium acetate were thoroughly mixed with the upper half of the soil in each pot, although the rates of application were based on the total weight of soil in the pot. The millet was planted on July 3, 1942, and the seedlings were thinned to seven uniformly spaced plants when they were 2 to 4 inches high. The moisture content of the soil was maintained at a uniform level by daily applications of tap water. The plants (aerial portions) were harvested on August 28, dried in a forced-draft oven at 150° F for 48 hours, and exposed to the laboratory atmosphere for several days before they were weighed.

As shown in Fig. 1, applications of sodium acetate at rates up to 840 pounds per acre had little or no effect on the dry-weight yields of

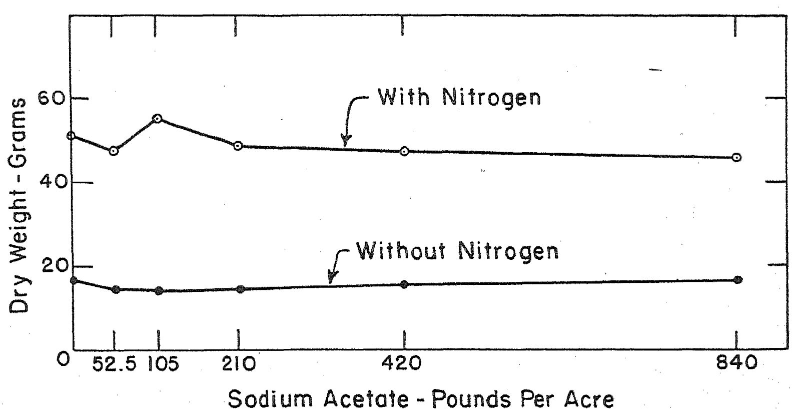

FIG. 1.—Effect of sodium acetate on growth of German millet.

millet in either the presence or the absence of nitrogen fertilizers. Also, the acetate-treated plants did not differ greatly from the controls in their development and appearance.

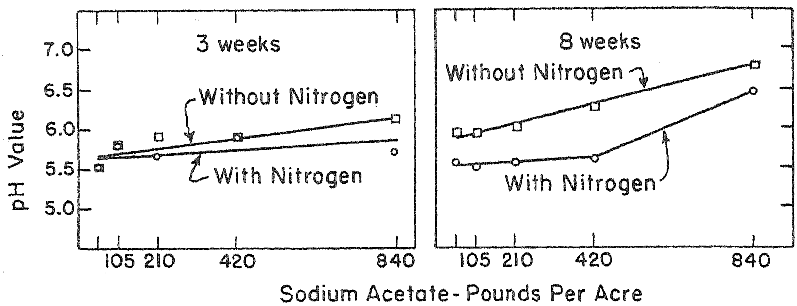

FIG. 2.—Effect of sodium acetate on soil pH value.

By means of the glass electrode, the pH values of 1:1 aqueous suspensions of 10-gram samples of soil from the center upper portion of each pot were determined at 3 and 8 weeks, respectively. In the absence of nitrogen fertilizer, the effect of the sodium acetate was to increase the pH value of the soil, usually in proportion to the quantity of sodium acetate applied (Fig. 2). The effect was much more pronounced at 8 weeks than at 3 weeks, probably owing to the greater decomposition of the acetate ion during the longer period of its contact with the soil. In the presence of nitrogen fertilizer, the pH value of the soil during the first 3 weeks tended to increase slightly with increase in the quantity of sodium acetate applied; at 8 weeks, however, the pH values of all the cultures, except those with 840 pounds of sodium acetate, were nearly identical and were generally somewhat lower than those of the same culture at 3 weeks. It appears that with the longer period of incubation the soil acidifying effect of the ammonium sulfate was approximately counterbalanced by the total alkalizing effect of the sodium nitrate and the sodium acetate at levels up to 420 pounds of the latter.—EILIF V. MILLER AND K. D. JACOB, *Division of Soil and Fertilizer Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Beltsville, Md.*

GREENHOUSE SEED TREATMENT STUDIES ON HEMP

HEMP was designated by the U. S. Dept. of Agriculture as a "War Crop" for 1943 and a program production goal of 300,000 acres was planned. The annual average production of hemp in the United States for fiber use in twines and cordage for the period 1929 to 1938 was less than 2,000 acres. In order to plant the large acreage desired in 1943, the Department of Agriculture contracted in 1942 with Kentucky farmers for 37,000 acres of hemp solely for seed production. The seed yields in 1942 were not as large as anticipated being only sufficient for planting approximately 185,000 acres for fiber

production. The germination of some lots of seed was low due to immature harvesting and adverse weather conditions which prevented early threshing. In order to utilize the seed as advantageously as possible for fiber production in 1943, questions arose regarding the value of seed treatment. There is little recorded evidence to indicate that hemp has been troubled by seedling diseases and seed treatments have not been recommended in the past for this crop. The Bureau of Plant Industry, Soils, and Agricultural Engineering was requested to determine benefits, if any, of seed treatment for hemp.

Results are presented in Table 1 reporting greenhouse tests arranged with the following cooperators: Dr. Benjamin Koehler, Agricultural Experiment Station, Urbana, Ill.; Howard V. Jordan, U. S. Dept. of Agriculture and Agricultural Experiment Station, Madison, Wis.; Dr. Richard Weindling, U. S. Dept. of Agriculture and Agricultural Experiment Station, Clemson, S. C.; Dr. J. A. Pinckard, Agricultural Experiment Station, State College, Miss.; and R. W. Leukel, U. S. Dept. of Agriculture Plant Industry Station, Beltsville, Md. Data obtained by other experiment stations cooperating in the tests seemed to be in line with those presented here.

The seed lots used were Kentucky-produced seed of high, medium, and low germination. The lots of seed tested in Wisconsin, Mississippi, and South Carolina were identical, and the Maryland and Illinois experiments had other lots that were identical. The greenhouse temperatures were similar for all locations, ranging from approximately 65° to 70°F. The choice of dusts for the experiments was the selection of the individual cooperators. The data in Table 1 are an average of three replications in Wisconsin, Mississippi, and South Carolina; four replications in Illinois; and five replications in Maryland. The treatments were randomized in Wisconsin, Mississippi, and South Carolina, but systematically arranged in Maryland and Illinois. Recorded results are on the number of seedling plants that emerged per 100 seeds planted. Despite systematic arrangement at two locations, analyses of variance were made throughout in order to obtain approximate differences required for significance.

In general, it appears that emergence from seed treated with any of the dusts at recommended rates may be expected to be better than that obtained from untreated seed. Evidence of Ceresan damage was obtained in the Wisconsin studies, but with an equal or heavier application at Beltsville, Md., no evidence of such damage was indicated.

Hemp seed for sowing has been sold to farmers at prices ranging from $5.00, to above $10.00 per bushel of 44 pounds. For fiber production the recommended rate of sowing is 55 pounds of seed per acre. Seed treatment of seed as valuable as hemp seed may well be worthwhile. In the production of hemp a contracting hemp processing mill usually distributes all seed to contract growers. This system of production makes it easily possible for the hemp mills to arrange for uniform seed treatment expertly supervised at centralized locations and at minimum expense due to the large bulk handled. It saves the grower the trouble of doing the job at a season when his time is needed for other jobs.

TABLE 1.—*A summary of data from greenhouse studies on hemp seed treatments.*

Treatment	Rate of application, ounces per bushel						Emergence, %					
	Wis.	Miss.	S. C.	Md.*	Md.*	Ill.	Wis.	Miss.	S. C.	Md.*	Md.*	Ill.
	Seed Lot No. 1763			Seed Lot No. 6219								
No treatment	—	—	—	—	—	—	63.7	36.3	66.3	61.8	63.6	65.5
Ceresan 2%	—	3.5	3.5	—	—	—	—	44.3	74.3	—	—	—
N. I. Ceresan 5%	2.8	—	3.5	5.0	0.5	0.5	52.0	—	69.3	87.0	84.4	84.8
N. I. Semesan Jr. 1%	0.8	—	—	—	—	—	73.3	—	—	—	—	—
Spergon	11.3	21.8	7.0	20.0	2.0	1.5	80.7	46.0	72.3	81.8	73.2	83.5
Cuprocide	9.7	22.5	7.0	—	—	—	78.7	48.3	72.7	—	—	—
Copper carbonate	—	—	—	20.0	2.0	—	—	—	—	76.8	71.6	—
Zinc oxide	—	24.6	14.1	—	—	—	—	49.7	70.3	—	—	—
Arasan	1.2	4.2	—	20.0	2.0	1.0	79.0	40.7	—	74.2	75.2	82.3
Fermate	—	—	—	—	—	1.5	—	—	—	—	—	86.8
Barbak D	—	—	—	—	—	1.5	—	—	—	—	—	82.5
	Seed Lot No. 2142			Seed Lot No. 6190								
No treatment	—	—	—	—	—	—	53.7	38.3	55.7	45.6	44.8	47.8
Ceresan 2%	—	3.5	3.5	—	—	—	—	38.7	63.3	—	—	—
N. I. Ceresan 5%	2.8	—	3.5	5.0	0.5	0.5	45.3	—	53.3	56.4	57.2	57.3
N. I. Semesan Jr. 1%	0.8	—	—	—	—	—	53.7	—	—	—	—	—
Spergon	11.3	21.8	7.0	20.0	2.0	1.5	58.0	37.7	59.7	53.6	51.8	58.8
Cuprocide	9.7	22.5	7.0	—	—	—	58.7	46.0	66.3	—	—	—
Copper carbonate	—	—	—	20.0	2.0	—	—	—	—	46.4	50.8	—
Zinc oxide	—	24.6	14.1	—	—	—	—	40.7	64.0	—	—	—
Arasan	1.2	4.2	—	20.0	2.0	1.0	53.3	33.0	—	53.2	56.4	52.3
Fermate	—	—	—	—	—	1.5	—	—	—	—	—	61.0
Barbak D	—	—	—	—	—	1.5	—	—	—	—	—	55.0

	Seed Lot No. 3136-½			Seed Lot No. 6215								
No treatment	—	—	—	—	—	—	24.0	19.0	24.0	19.8	20.6	13.5
Ceresan 2%	—	3.5	3.5	—	—	—	—	10.7	31.0	—	—	—
N. I. Ceresan 5%	2.8	—	3.5	5.0	0.5	0.5	16.3	—	31.0	18.6	17.4	24.5
N. I. Semesan Jr. 1%	0.8	—	—	—	—	—	35.0	—	—	—	—	—
Spergon	11.3	21.8	7.0	20.0	2.0	1.5	30.3	15.0	30.0	22.2	18.0	23.3
Cuprocide	9.7	22.5	7.0	—	—	—	27.3	29.3	29.3	—	—	—
Copper carbonate	—	—	—	20.0	2.0	—	—	—	—	21.4	26.0	—
Zinc oxide	—	24.6	14.1	—	—	—	—	20.3	31.3	—	—	—
Arasan	1.2	4.2	—	20.0	2.0	1.0	28.3	11.7	—	18.4	17.2	23.0
Fermate	—	—	—	—	—	1.5	—	—	—	—	—	25.8
Barbak D	—	—	—	—	—	1.5	—	—	—	—	—	22.3
Difference required for significance between treatments: Odds 99.1							18.0	20.6	14.6	8.5	8.5	8.9
Difference required for significance between treatments: Odds 19.1							13.3	15.3	10.9	6.3	6.4	6.7

*U. S. Dept. of Agriculture, Bureau of Plant Industry, Soils, and Agricultural Engineering, Beltsville, Md., two rates of application.

Variations in stands of plants of hemp do not necessarily indicate corresponding differences in total tonnage of hemp stalks per acre of ground. Experiments reported by Herzog,[1] together with unpublished data collected by the U. S. Dept. of Agriculture, have shown that sowings of 3, 4, and 5 pecks per acre resulted in no significant differences in yields of stalks. However, the thicker rates of seeding produced more plants and plants with smaller diameter stalks and higher fiber content. It is well recognized that the percentage of fiber in relation to wood in thin stems is greater than in thick stems. The increase of fiber under normal conditions between sowings of 3 to 5 pecks of seed per acre may amount to approximately 50 to 100 pounds more fiber per acre. This increased return makes it evident that seed treatment in addition to providing a saving in outlay for expensive seed may insure more productive yields of fiber per area of ground. —BRITTAIN B. ROBINSON, *Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Washington, D. C.*

[1]HERZOG, R. O. Hanf und Hartfasern. Technologie der Textilfasern V. Band, 2 Teil. 1927.

A METHOD FOR INOCULATING SMALL LOTS OF LEGUME SEED[1]

WHEN seed treatment studies involving several leguminous plants were begun at the Alabama Agricultural Experiment Station in 1940, certain results were obtained that suggested a time-saving method for the inoculation of numerous small lots of seed. The method proved so effective that it is now being used in the legume breeding nurseries at Auburn whenever inoculation of the seed is deemed advisable. It is also possible, by this method, to use legume inoculants in combination with seed disinfectants ordinarily considered to be lethal to root nodule organisms.

The method developed dispenses with the ordinary direct application of the inoculent to the seed. Rather, it is an indirect method involving the incorporation of commercial legume culture into finely-ground stable manure and application to the plot rather than to the seed.

A small-sized package of culture (for 100 to 120 pounds of seed) was thoroughly mixed into 300 pounds of well-composted, finely ground stable manure. The mixture was usually sacked and allowed to stand for 1 or 2 days, but it has been used effectively immediately after mixing or as long as 1 week after mixing. In the case of row crops, the inoculated manure was evenly applied to open furrows at the rate of 300 pounds per acre. The seed was dropped into the row directly in contact with the inoculated manure and covered. Small seed, such as crimson clover, was mixed into the inoculated manure and broadcast onto the plot prior to raking in or cultipacking. The crimson clover yields reported in Table 1 were obtained from plots sowed with seed treated in this manner.

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. This work was supported in part by a grant from The Nitragin Co., Inc., Milwaukee, Wis.

The indirect method of inoculation was proved to be effective on two summer legumes, peanuts and soybeans, and on three winter legumes, blue lupines, monantha vetch, and crimson clover.

The use of manure at such a low rate did not contribute to any apparent variability in growth within or between plots of the same treatment. In the instance of soybeans, the stand of soybeans was reduced when the seed was sowed in contact with manure, but injury of this nature was not evident in the case of the other crops included in the tests. The use of manure (uninoculated) appeared to have stimulated the yield of hay and nuts of Spanish peanuts, but the low incidence of nodules on the plants treated in this manner indicates this was not due to the occurrence of legume bacteria of the cowpea group in the manure used. Actually, the plants, like all those growing on the uninoculated plots, showed evidences of inoculation deficiencies as they approached maturity.

To test the effectiveness of the indirect method of inoculation further, seed treated with Ceresan was planted in contact with

TABLE 1.—*Yields of certain leguminous plants as affected by direct and indirect application of legume bacteria, Auburn, Alabama, 1942.**

Treatment	Yield, lbs. per acre†		No. nodules per 12 plant sample‡
	Hay	Nuts	
Peanuts			
None	2,800	1,260	13.25
Inoculated	2,979	1,517	239.25
Manure	2,866	1,419	8.50
Inoculated manure	3,174	1,551	173.50
Ceresan 2%	3,230	1,456	8.25
Inoculated manure plus Ceresan 2%	3,300	1,834	212.25
Soybeans			
None	2,760	—	—
Inoculated	2,840	—	—
Inoculated manure	2,880	—	—
Manure	2,240	—	—
Ceresan 2%	3,060	—	—
Inoculated manure plus Ceresan 2%	3,220	—	—
Blue Lupine§			
None	375	—	—
Inoculated	963	—	—
Ceresan 2%	338	—	—
Inoculated manure plus Ceresan 2%	1,238	—	—
Crimson Clover**			
None	7,147	—	—
Inoculated manure	17,016	—	—
Inoculated	16,335	—	—

*0–14–10 applied to all crops at rate of 300 lbs. per acre.
†Average of four 1/220-acre harvests.
‡Average of four 12-plant samples; nodules counted on 9-week-old seedlings.
§Yields given are green weights; low yields are a consequence of severe winter injury.
**Yields given are green weights; average of four 1/5445 acre cuttings.

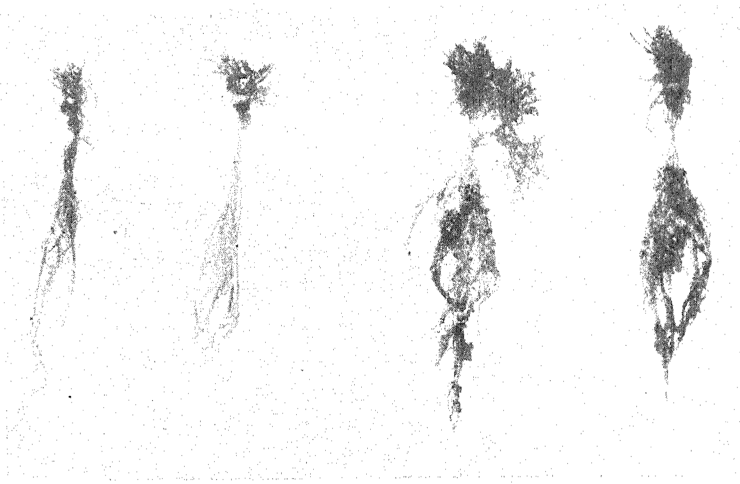

FIG. 1.—Monantha vetch plants dug 5 months after planting. Left, uninoculated; right, planted in contact with inoculated manure. Seed treated with Ceresan in both cases.

inoculated manure. Nodulation was readily accomplished despite the use of this mercury compound, and, from the standpoint of

FIG. 2.—Blue lupine plants dug 5 months after planting. Left, uninoculated; right, planted in contact with inoculated manure. Seed treated with Ceresan in both cases.

yields obtained, the treatment proved to be the most effective of all employed (Table 1, Figs. 1 and 2).

The yields of plots planted with seed inoculated by the indirect method were equal to those planted with seed inoculated in the usual manner in the case of soybeans and crimson clover. In the case of peanuts, the yields of plots planted with seed inoculated by the indirect method were, by statistical analysis, significantly greater than those of plots planted with seed to which the inoculation was applied directly. Although no direct comparison between the two methods was made with blue lupines, the yields of plots planted with seed inoculated by the indirect method and treated with Ceresan were significantly greater than those planted with uninoculated or directly-inoculated seed.—H. R. ALBRECHT, *Alabama Agricultural Experiment Station, Auburn, Alabama.*

AGRONOMIC AFFAIRS

PRESIDENT KEIM ISSUES STATEMENT ON THE ANNUAL MEETING

THE annual meeting of the American Society of Agronomy will be held November 10 to 12, 1943, in Cincinnati, Ohio.

In 1917, W. M. Jardine in the December number of the JOURNAL (Volume 9) made the following statement: "Upon our entry into the war, the government had need of the immediate services of every industry, every organization, and every individual, and the response came promptly and loyally from every quarter. Agronomists at once evinced an all-pervading desire to bring to the immediate assistance of the country every ounce of their strength which might be put to practical use. They frequently proved to be the logical men to form "ways and means" committees for devising plans whereby the maximum production could be secured from every man, every horse, every machine, and every acre of ground, quickly, and at the same time jeopardize in no way the permanence of agriculture. Campaigns for increased crop acreages were initiated and carried to successful completion. Seed stocks were inventoried and made available for those in need. Information on every conceivable point relating to agriculture was given to the public through correspondence, public addresses, and the press. This successful participation of agronomists in emergency work is a splendid tribute to their usefulness. It will be continued with increasing vigor."

The agronomists of 1943 have the same responsibility. It is for like reasons that the Executive Committee of the Society feels that the 1943 annual meeting of the Society should be held. Our annual meeting is not a convention, but it is a gathering of scientific workers who probably contribute as much to the food effort of the world as any other organization. The agronomists in every state and in the U. S. Dept. of Agriculture have the responsibility of promoting food production to the maximum. It is the opinion of the officers of the Society that the best interests of the food effort will be served

by holding a meeting, where the knowledge of one becomes the common knowledge of all.

Might I urge each state and the U. S. Dept. of Agriculture to make every possible effort to be well represented at the annual meeting which convenes in Cincinnati on November 10, 1943. The more whole-hearted support given by the membership, the greater will be the benefits derived.

The program committees have arranged excellent programs. The speakers for the general program on Thursday morning will be Dr. L. A. Maynard of the School of Nutrition, Cornell University, who will speak on "The Soil and Crop Basis of Better Nutrition" and Dr. O. E. May, chief of the processing laboratories, U. S. Dept. of Agriculture, who will summarize some of the more important phases of research conducted in these laboratories which relates to the present and future war effort.—F. D. KEIM, *President of the American Society of Agronomy.*

NEWS ITEMS

ROBERT L. CUSHING, formerly of the Agronomy Department of the University of Nebraska, has been appointed Assistant Professor of Plant Breeding at Cornell University. Recently Professor Cushing was also associated with the Bureau of Plant Industry, U. S. Dept. of Agriculture, and had charge of the grain sorghum investigations for the Nebraska region.

—A—

THE FOLLOWING changes in personnel are reported from the Florida Agricultural Experiment Station at Gainesville:

DOCTOR GORDON B. KILLINGER, formerly Associate Agronomist has been named Agronomist in place of Doctor W. A. Leukel, who died April 27. DOCTOR H. C. HARRIS was named Associate Agronomist, effective September 15. DOCTOR ROGER W. BLEDSOE was named Associate Agronomist, effective September 1. G. T. SIMMS has been appointed Associate Chemist in the Soils Department. DOCTOR ERNEST L. SPENCER has been appointed Soils Chemist at the Vegetable Crops Laboratory at Bradenton. RAYMOND C. BOND has been appointed Assistant Agronomist at the North Florida Experiment Station at Quincy.

—A—

ACCORDING TO *Science*, Doctor E. B. Fred was recently appointed Dean of the College of Agriculture of the University of Wisconsin. Doctor Fred has been Dean of the Graduate School at the University for the past nine years.

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METHODS OF DETASSELING AND YIELD OF HYBRID SEED CORN[1]

CARL BORGESON[2]

FROM observation, methods of detasseling vary from the seed grower who goes over his crossing plot many times removing only the most advanced tassels each trip, to the producer who waits as long as is safe before beginning detasseling and then attempts to detassel as many plants as possible the first time over the field. The removal of tassels that have not entirely emerged from the leaf sheath is practically impossible without removing at the same time one or two of the upper leaves. Hybrid seed corn producers have asked whether the removal of leaves with the tassel had an effect on seed yields.

Dungan and Woodworth[3] found that the removal of one, two, three, and four leaves with the tassel reduced the yield of grain 8.3, 15.3, 18.1, and 29.2%, respectively. They reviewed previous studies of the effect of detasseling on yield in corn.

The experiment reported here was started in 1940 to determine what effect the removal of different numbers of leaves had on seed yield and whether differences existed among female parents of different hybrids.

MATERIALS AND METHODS

In 1940, seed stocks of a number of new Minhybrid double crosses were released to Minnesota producers. Six of these double crosses had as a common male parent the single cross A7×A12. This fact enabled seed producers to produce seed of Minhybrids 700 and 701, maturity rating 88 to 92 days; Minhybrids 600 and 601, maturity rating 95 to 101 days; and Minhybrids 500 and 501, maturity rating 103 to 109 days, in one isolated plot. Since the female parents of these varieties varied considerably in maturity and plant habit, particularly width of leaf and type of tassel, this material seemed admirably suited for a study of the effect of leaf removal within and between varieties.

A well-isolated plot of ground that had been in pasture for a number of years was selected for the experiment. Three blocks of four rows each of each female

[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 2090 of the Journal Series, Minnesota Agricultural Experiment Station. Received for publication May 29, 1943.

[2]Assistant Professor in Agronomy.

[3]DUNGAN, G. H., and WOODWORTH, C. M. Loss resulting from pulling leaves with the tassels in detasseling corn. Jour. Amer. Soc. Agron., 31:872–875. 1939.

parent were planted with two male rows between the blocks as a pollinator. This made a total of 12 rows of each female with 40 hills in each row. The male and female parents were planted at the same time, with the exception of Minhybrids 500 and 501 where the female parents were planted several days before the male parent. Five kernels were planted per hill and the hills thinned to three stalks.

Four methods of detasseling were used in the studies, as follows: (1) No leaves removed with the tassel; (2) one leaf removed with the tassel; (3) two leaves removed with the tassel; and (4) three leaves removed with the tassel. The methods of detasseling were randomized within each female parent, but the female parents were planted in a systematic order in the field.

In harvesting, only full stand hills surrounded by corn were selected and the yields per acre determined for these on a 14% moisture basis. The experiment began in 1940 and was repeated on the same field in 1941 and 1942. The data were analyzed statistically by the analysis of variance method.

RESULTS

The 3-year results, giving bushels per acre for each hybrid and method of treatment as well as least significant differences in bushels, are given in Table 1.

It is apparent from the data in Table 1 that the removal of one leaf did not have a very harmful effect on yield, that when two leaves were removed the yield was significantly lower than when no leaves were removed for each year of the study, and that the removal of three leaves gave, on the average, a reduction in yield of 9.2 bushels per acre in comparison with the removal of no leaves.

To determine whether all hybrids reacted in the same manner to the removal of leaves in detasseling the average yields were calculated for the 3-year period for the four treatments. The data given in Table 2 are percentages of the yield of each hybrid when no leaves were removed. The least significant difference of percentages at the 5% point is expressed in percentage of the average yield when no leaves were removed.

The data in Table 2 show that the removal of one leaf with the tassel caused the greatest reduction in yield for the female parent of Minhybrid 601, although the difference of 6.5% was not significant statistically. The pulling of one leaf with the tassel for the other five hybrids gave only small differences in comparison with the removal of no leaves and two hybrids yielded slightly more when one leaf was removed than when no leaves were removed with the tassel. When two leaves were removed, the four early hybrids, 700, 701, 600, and 601, were reduced in yield from 6.8 to 13.9%. The Minhybrid 701 female parent gave a significant reduction in yield when two leaves were removed as compared with the removal of one leaf. The later maturing broad-leaved parents of 500 and 501 were only slightly reduced in yield by removing two leaves. When three leaves were removed, the two last-named varieties gave the decided reductions in yield in comparison with the removal of no leaves of 10.1 and 12.7%, respectively. The four earlier maturing parents were reduced in yield from 16.6 to 26.8% by the removal of three leaves when compared with the removal of no leaves in detasseling.

TABLE 1.—*Yield in bushels per acre from six corn hybrids for each of three years in relation to the number of leaves removed with the tassel.**

Hybrid	Number of leaves removed			
	0	1	2	3
1940				
500	57.7	58.8	54.6	51.8
600	48.0	45.8	43.0	38.0
601	46.2	43.6	42.2	36.4
700	47.2	43.2	38.6	36.0
701	45.8	42.8	39.0	33.4
Average	49.0	46.8	43.5	39.1
1941				
500	63.8	64.5	62.8	56.2
501	64.8	67.6	62.4	57.0
600	53.2	54.0	51.8	49.4
601	51.2	46.8	45.8	41.4
700	50.4	49.4	46.6	42.0
701	51.2	51.4	47.0	42.4
Average	55.8	55.6	52.7	48.0
1942				
500	41.8	43.0	42.0	38.6
501	46.8	44.6	45.4	40.4
600	43.4	40.4	39.8	33.2
601	41.6	39.6	34.8	28.4
700	37.4	37.0	34.8	25.4
701	37.0	36.4	29.6	22.4
Average	41.4	40.2	37.8	31.4
Average of averages, 1940–42	48.7	47.5	44.7	39.5
Least significant differences in bu. at 5% point for average of the varieties:				
1940	2.39			
1941	2.64			
1942	2.96			
Average, 1940–42	1.52			

*Minhybrid 501 was not included in 1940.

SUMMARY

The effect on yield of seed of the removal of no leaves and of one, two, and three leaves in detasseling was compared for six hybrids, five of these being tested during three years and the other for two years only.

The removal of one leaf with the tassel when detasseling gave only a slight reduction in yield when compared with the removal of no leaves. A statistically significant difference was obtained between the

TABLE 2.—*Average yield in bushels per acre of six hybrids for the four treatments expressed in percentages of the yield of each hybrid when no leaves were removed.**

Hybrid	0 leaves removed		1 leaf removed		2 leaves removed		3 leaves removed	
	Bushels per acre	%	Bushels per acre	%	Bushels per acre	%	Bushels per acre	%
500	54.4	100	55.4	101.8	53.1	97.6	48.9	89.9
501	55.8	100	56.1	100.5	53.9	96.5	48.7	87.3
600	48.2	100	46.7	96.9	44.9	93.2	40.2	83.4
601	46.3	100	43.3	93.5	40.9	88.3	35.4	76.5
700	45.0	100	43.2	96.0	40.0	88.9	34.5	76.7
701	44.7	100	43.5	97.3	38.5	86.1	32.7	73.2

*Least significant difference of percentages at the 5% point = 7.60.

removal of two leaves and no leaves for Minhybrids 601, 700, and 701. Each of the six hybrids gave a marked reduction in yield when three leaves were removed in detasseling compared with the removal of no leaves, the average difference in bushels being 9.2.

The early maturing varieties gave the greatest reductions in yield due to the removal of leaves with the tassel in detasseling. The removal of two leaves in detasseling gave only a small reduction in yield for two later hybrids that had female parents with a relatively high leaf area.

FACTORS AFFECTING THE SUCCESS OF POLLINATION IN CORN[1]

JOHN H. LONNQUIST AND R. W. JUGENHEIMER[2]

ADVERSE weather during the critical flowering period of corn, *Zea mays* L., is perhaps one of the greatest hazards to corn production in the Great Plains area. High temperatures and extreme desiccation, or both, may blast the entire tassel or kill the pollen grains after they are shed, or may otherwise interfere with pollination by causing the silks to wilt rapidly, thus hastening the loss of their receptiveness to pollen. This interference with the pollination process is reflected in poorly pollinated ears at harvest and consequently a reduction in the yield of grain.

Previous work at the Kansas Agricultural Experiment Station (4, 5)[3] has shown that the leaves of some inbred lines and hybrids fire badly at relatively low temperatures, while others growing alongside may remain green through severe periods of drought. These studies also indicated that most hybrids that are resistant to leaf firing have an advantage in yield of grain over susceptible types during years when severe droughts occur. Corn hybrids resistant to leaf firing, however, may frequently produce low yields. It appears, therefore, that the reduction in yield may be due to interference with normal fertilization as well as injury sustained by the vegetative portion of the plant. It seemed desirable to study some of the factors affecting grain yield under drought conditions. The primary objective was to determine how seed setting in corn is affected by temperature, age of silks, and source of pollen, and how these factors are conditioned by soil moisture and the drought reaction of the material.

MATERIALS AND METHODS

The effect of daily maximum temperatures upon seed setting was studied in 1940 and 1941 on a total of over 7,000 self-pollinations. In 1940, 15 inbred lines were grown for increase in a plot that could be irrigated with an overhead sprinkler system. Success of pollination was estimated as the percentage of the ovules on the ear developing into mature seeds. These data from more than 2,000 ears were correlated with the maximum temperature on the day of pollination. The daily temperatures were obtained from the U. S. Weather Bureau report for Manhattan, Kans. Similar data were obtained in 1941 on some 5,100 ears produced under irrigation. A wide range of breeding material was represented by including lines involved in commercial or promising experimental hybrids from 17 states. Temperature and humidity records in 1941 were obtained from

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[1]Department of Agronomy, Kansas Agricultural Experiment Station, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, cooperating. Contribution No. 346, Department of Agronomy. Received for publication June 7, 1943.

[2]Formerly Agent and Associate Agronomist, respectively, Division of Cereal Crops and Diseases.

[3]Figures in parenthesis refer to "Literature Cited", p. 933. Also, unpublished data by R. W. Jugenheimer on resistance of corn strains to leaf firing.

a recording hygro-thermograph located in the irrigated plot about 4 feet above the soil.

Six inbred lines differing in resistance to leaf firing and the 15 possible single crosses among them were used in studying the duration of silk receptivity. The material was grown on dry land and under irrigation in 1941. Plantings were made at regular intervals for a period of 1 month to insure a spread in silking of about 3 weeks. The young ear shoots were covered with parchment paper bags, before the silks appeared, to prevent natural pollination. The upper shoot was used in these studies, but all shoots were covered to prevent any possible change in the physiology of the upper shoots that might result from the fertilization of the lower ones. The number of days elapsing from the initial emergence of the silk until it was exposed to pollen was used as the silk age. Silks emerging first were held for the longest time and all were exposed on the same day to pollen from the single cross, Wf9×38-11. The harvested ears were classified into 10 grades based on the percentage of the ovules on the ear developing into mature seeds. A grade of 1 indicated 1 to 10% of seed set, a grade of 10 indicated 91 to 100%, and the eight intervening grades referred to corresponding percentages of seed set.

Three plants of each line and single cross used in the silk receptivity studies were used in studying the rate and persistance of silk growth. The amount of new growth was measured in centimeters every second day after which the silks were clipped back to the tip of the husks. This procedure was continued until no further growth occurred.

Twenty-five inbred lines grown under irrigation were used for studying the probable existence of differential fertilizing ability of pollen. On the basis of previous information on their resistance to leaf firing, 14 of these lines were classed as resistant and 11 as susceptible. Pollen of each line was placed the same day on randomly selected silks of Wf9×38-11. Each ear was graded at harvest for percentage of full seed set.

EXPERIMENTAL RESULTS

The relative amounts of seed obtained in 1940 and 1941 on inbred lines grown under irrigation and self pollinated on days differing in their maximum temperatures are shown in Table 1. The higher average seed set in 1941 for similar temperatures was due primarily to the higher humidity during that summer. Also, temperatures during the 1941 pollinating season never exceeded 103° F. This, together with the higher humidity, probably prevented the rapid drying out of silks and pollen. In each season poor seed setting on the self-pollinated ears was significantly associated with high daily temperatures on the day of pollination. A few lines set seed well at the highest recorded temperatures, while others had low set at relatively optimum temperatures. Obviously, these better lines have a specific advantage under drought conditions.

The average percentage of seed set on lines pollinated on days of different maximum temperatures is shown by a freehand curve in Fig. 1. As an average of 2 years, seed setting ranged from 65% to only 8% when the maximum temperature on the day of pollination ranged from 80° to 110° F, respectively. The apparent failure of pollination at the higher temperatures is believed due, primarily, to

TABLE 1.—*Percentage of ovules setting seed on inbred lines of corn grown under irrigation and self pollinated on days differing in their maximum temperatures.*

Daily maximum temperature, °F	1940		1941		Mean	
	No. of pollinations	Average seed set, %	No. of pollinations	Average seed set, %	No. of pollinations	Average seed set, %
76°–80°	—	—	186	64.8	186	64.8
81°–85°	10	44.0	163	64.5	173	54.2
86°–90°	388	26.4	1,536	65.3	1,924	45.8
91°–95°	263	24.5	1,485	45.3	1,748	34.9
96°–100°	330	24.9	1,442	44.1	1,772	34.5
101°–105°	634	7.6	297	32.0	931	19.8
106°–110°	440	8.2	—	—	440	8.2
Total.......	2,065	—	5,109	—	7,174	—
Correlation coefficient.		−0.93**		−0.89*		

*Significant.
**Highly significant.

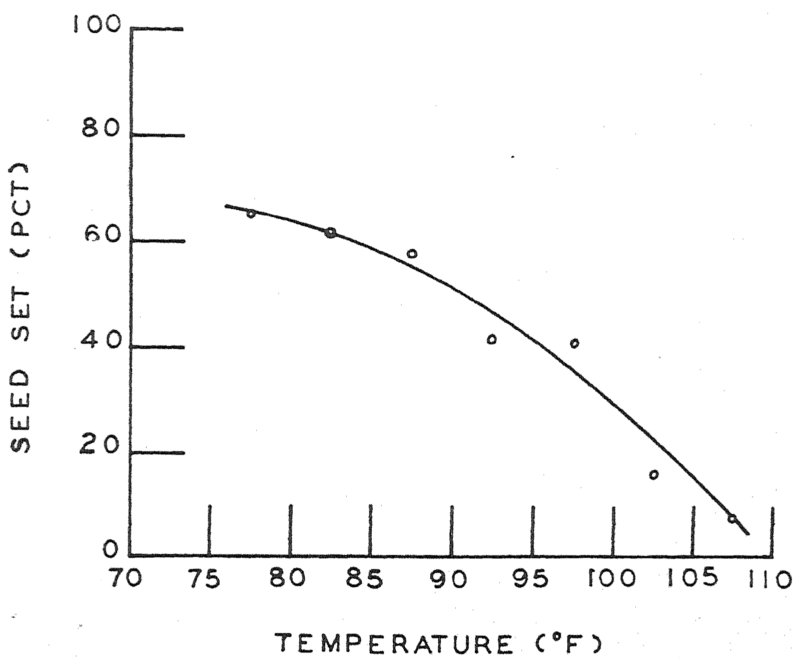

FIG. 1.—Percentage of ovules setting seed on ears of inbred lines of corn grown under irrigation and self pollinated on days differing in their maximum temperatures. Average of 1940 and 1941.

the rapid desiccation of the pollen and silks rather than to the lethal effect of high temperatures.

Pollen is subject to drying from the time of dehiscence until germination and growth into the silk is completed. Where conditions are unfavorable, the pollen grains might be easily killed by desiccation before fertilization is accomplished. White porous cup atmometers placed at various heights in a corn plot during the 1941 growing

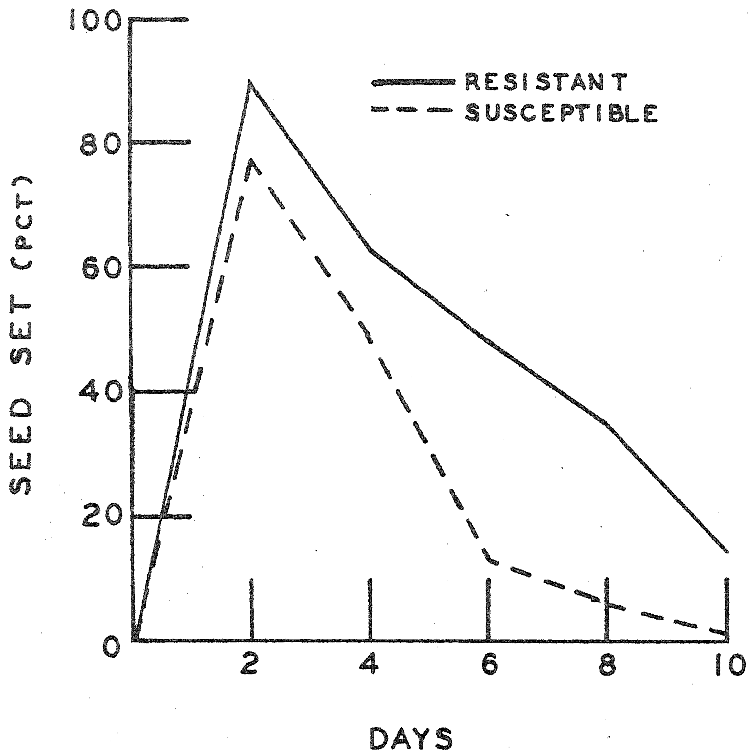

FIG. 2.—Duration of receptiveness of silks to pollen of six inbred lines of corn differing in resistance to leaf firing and compared on dry land and under irrigation, Manhattan, Kans., 1941.

season showed that evaporation decreases from the level of the tassel downward. The tassel, therefore, is subject to more severe drying than is the ear shoot or any other part of the plant. Also, because no shade is afforded the tassels, temperatures are higher there than in the silk region where considerable shading occurs.

Data on the duration of silk receptivity of inbred lines and single crosses are given in Tables 2 and 3, respectively. The mean seed set obtained from the two locations plotted graphically in Figs. 2 and 3 shows that the maximum seed set was obtained when silks were exposed to pollen 2 days after emergence and that it declined rapidly

thereafter for each additional 2-day period they were withheld from pollen. Lines and hybrids resistant to leaf firing set more seed for each silk age and their silks remained receptive longer than did those of susceptible stocks. If the leaves of resistant plants have the property of resisting water loss, there is good reason to believe that their pollen and silks also may have similar properties.

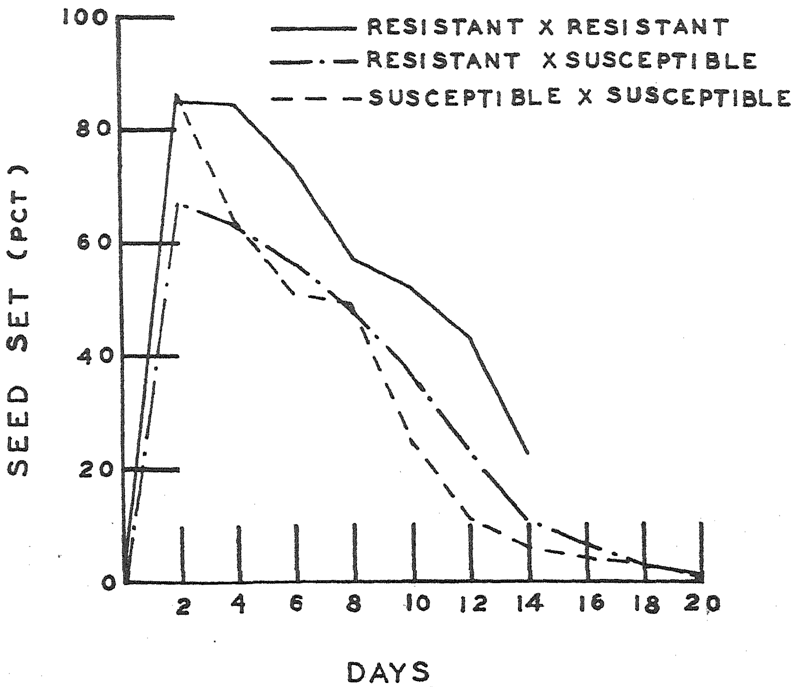

FIG. 3.—Duration of receptiveness of silks to pollen of the 15 single crosses among six inbred lines of corn differing in resistance to leaf firing and compared on dry land and under irrigation, Manhattan, Kans., 1941.

Extensive unpublished data (5) at the Kansas Experiment Station indicated a positive correlation between resistance to leaf firing and high grain yield. Thus, the available evidence indicates that in selecting material for drought resistance, i.e., on the basis of resistance to leaf firing, selection for material that has an advantage in pollination during periods of stress is accomplished also.

The effectiveness of ample soil moisture in prolonging silk receptivity differed for the inbred lines and the single crosses used in this study (Tables 2 and 3). There was no significant difference in the amount of seed set on inbred lines grown under irrigation and those grown on dry land. The single crosses, on the other hand, set significantly more seed when grown under irrigation. All three groups of crosses (resistant×resistant, resistant×susceptible, and susceptible ×susceptible) reached the limit of receptivity at 16 days under dry-

TABLE 2.—*Duration of receptiveness of silks to pollen of six inbred lines of corn differing in resistance to leaf firing and compared on dry land and under irrigation, Manhattan, Kans., 1941.*

Location	Percentage of seed set when silks were the indicated number of days old						
	2	4	6	8	10	12	14
			Resistant Class				
Irrigated...	80.0	63.7	49.4	35.6	21.2	11.7	—
Dry land...	90.0	60.8	67.1	35.0	12.5	6.2	—
Mean......	89.0	63.2	58.2	35.3	16.8	9.0	—
			Susceptible Class				
Irrigated...	66.7	48.0	16.7	5.6	0.6	—	—
Dry land...	87.5	49.1	10.0	6.7	1.4	—	—
Mean......	77.1	48.6	13.4	6.2	1.0	—	—

Analysis of Variance†

Source of variation	D/F	Mean square
Leaf firing class..............	1	1381.12*
Silk ages.....................	4	1528.90*
Class × silk age...............	4	96.20
Location......................	1	23.33
Interactions:		
Class × location.............	1	0.24
Silk age × location..........	4	28.94
Error.........................	4	23.97

*Significant.
†Analysis of variance computed from above data by converting the percentage figures to degrees. Percentage (P) $= \sin^2 \theta$.

land conditions. The summer drought became so acute at this time that all material grown on dry land fired badly within the period of a few days. This prevented the expression of any differential duration of silk receptivity which otherwise might have occurred among groups.

When the same material was grown under irrigation, however, the plants did not fire badly and the decline in silk receptivity was not nearly so rapid. Seed was set on silks up to 20 days old for crosses involving susceptible lines. The resistant × resistant crosses flowered somewhat later than plants of the other groups so that the oldest silks of this group of crosses were 14 days old when exposed to pollen. Comparisons of seed set for silks up to 14 days old show that the resistant × resistant crosses had a distinct advantage in seed set over the groups involving susceptible material.

A comparison of temperatures and humidity taken in the corn plots at both locations showed that under irrigation the maximum temperatures were lower and the relative humidity higher than in corn growing on dry land. Thus, where ample soil moisture was provided by irrigation, the severity of the surrounding environmental

TABLE 3.—*Duration of receptiveness of silks of the single crosses among six inbred lines of corn differing in resistance to leaf firing and compared on dry land and under irrigation, Manhattan, Kans., 1941.*

Location	Percentage of seed set when silks were the indicated number of days old										
	2	4	6	8	10	12	14	16	18	20	22
					R×R Class						
Irrigated . .	92.5	91.0	82.0	72.0	69.0	53.0	32.0	—	—	—	–
Dry land. .	77.1	77.9	64.0	42.9	35.2	32.4	12.1	4.3	0.0	0.0	0.0
Mean.	84.8	84.4	73.0	57.4	52.1	42.7	22.0	—	—	—	–
					R×S Class						
Irrigated . .	93.1	82.5	73.1	62.0	52.4	36.2	24.7	13.4	6.3	2.1	0.0
Dry land. .	40.0	43.0	39.7	34.8	22.5	9.8	7.1	1.1	0.0	0.0	0.0
Mean.	66.6	62.8	56.4	48.4	37.4	23.0	15.9	7.2	3.2	1.0	0.0
					S×S Class						
Irrigated . .	92.5	81.9	62.3	64.0	39.0	17.2	10.0	7.7	5.0	1.2	0.0
Dry land. .	80.0	46.0	39.3	34.0	11.7	5.7	1.7	0.9	0.6	0.0	0.0
Mean.	86.2	64.0	50.8	49.0	25.4	11.4	5.8	4.3	2.8	0.6	0.0

Analysis of Variance†

Source of variation	D/F	Mean square
Leaf firing class.	2	5656.85**
Silk age.	6	1462.28**
Class×silk age.	12	42.14*
Location.	1	2886.75**
Interactions:		
Class×location.	2	50.21
Silk age×location.	6	10.73
Error.	12	15.64

*Significant.
**Highly significant.
†Analysis of variance computed from above data by converting the percentage figures to degrees. Percentage (P) = $\sin^2 \theta$.

conditions also was noticeably lessened. The more favorable seed setting under irrigated conditions, therefore, was due not only to the presence of sufficient soil moisture itself, but also to its effect in moderating the temperature and the evaporating power of the air around the plants.

The rate of silk growth of lines and single crosses for successive 2-day intervals was studied in 1941 in connection with the receptivity studies in an attempt to determine the rapidity with which any given region of a silk lost its receptivity after emergence from the husks. Coefficients of correlation computed between seed set and silk growth for both the inbred lines and single crosses were +0.79 and +0.83, respectively. Thus, the highest seed set (Figs. 2 and 3) and the greatest growth of silks (Figs. 4 and 5) occurred about 2 days after the

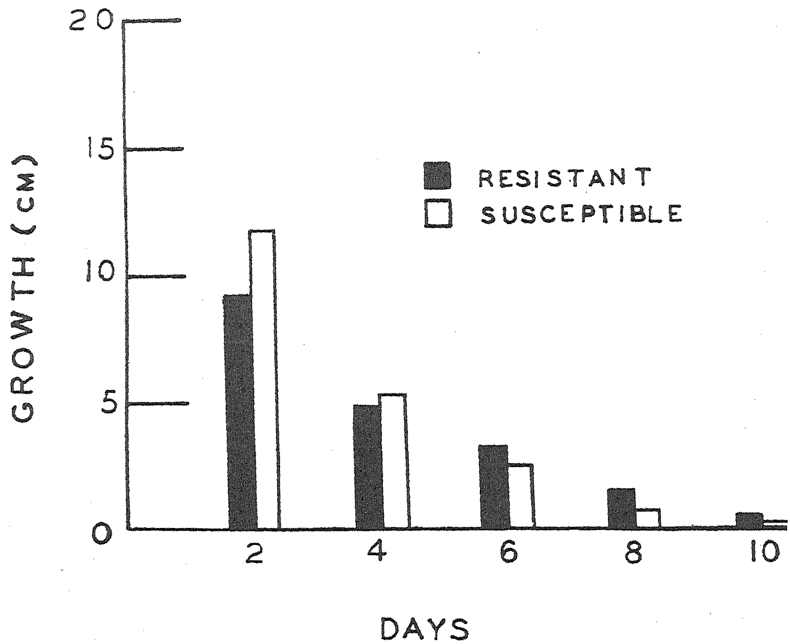

FIG. 4.—Persistance of silk growth during successive 2-day intervals of six inbred lines of corn differing in resistance to leaf firing, Manhattan, Kans., 1941.

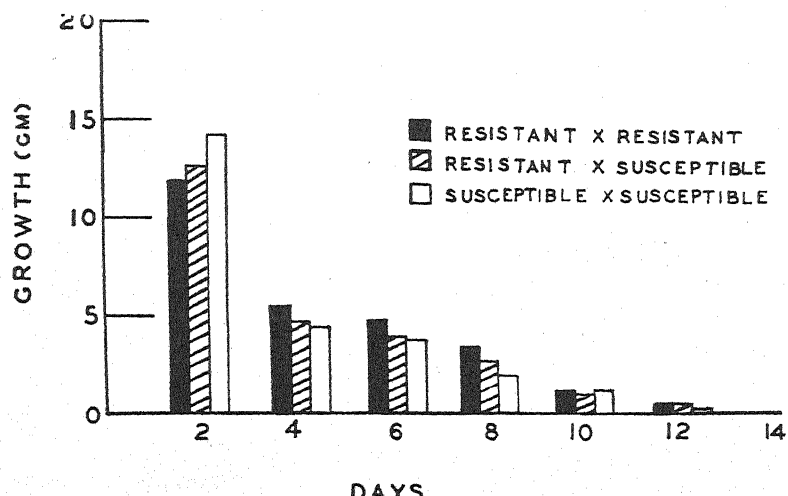

FIG. 5.—Persistance of silk growth during successive 2-day intervals for the 15 single crosses among six inbred lines of corn differing in resistance to leaf firing. Manhattan, Kans., 1941.

silks emerged from the husks. As the silk growth declined thereafter, the amount of seed set diminished correspondingly. It should be mentioned here that the entire silk brush does not and did not continue growth for the period indicated. The silks from the tip florets were the last to emerge and were apparently much slower growing than those from the central portion of the ear. These silks are responsible for the growth observed after the main brush of silks had ceased growth. Whether the apparent slower growth of the later emerging silks was due to injury sustained by clipping is not known. It may, however, be partly responsible for this behavior. The growth of the main brush of silks ceased after about 6 days following emergence. This corresponds closely with the rapid decline in seed setting when silks older than 6 days are pollinated. Apparently the loss of receptivity for any given portion of a silk is very rapid under conditions such as prevailed during the course of these studies.

Jones (3) suggested that the pollen and silks of certain lines may be incompatible when crossed. An excellent example of cross-incompatibility in corn is that of lines from two popcorn varieties used in the popcorn breeding work at Manhattan, Kans. Crosses between lines of Supergold and those from South American Varieties can be made only when South American lines are used as the pollen parent. When the reciprocal cross is attempted, no seed set results. Causal observa-

TABLE 4.—*Differential fertilizing ability of pollen of 25 inbred lines of corn when placed on silks of the single cross, Wf9×38–11.*

Resistant to leaf firing		Susceptible to leaf firing	
Line	Percentage seed set	Line	Percentage seed set
K 201A	82.5	Ind. 66–24	89.0
K 148	72.5	K 26	79.0
K 17	72.5	K 14	75.0
K 8	71.0	Iowa Bl 349	75.0
K 55	70.0	K 151	65.0
Ind. 38–11	67.0	K 20	62.0
K 130	65.0	K 214	60.0
U. S. 187–2	63.0	K 5	51.0
Iowa L 317	58.0	K 131	45.0
K 10	50.0	K 249	42.5
K 153	41.0	K 61	37.0
Ind. Wf9	32.0		
K 18	14.0		
K 167	12.0		
Mean	55.2	Mean	61.9

Analysis of Variance

Source of variation	D/F	Mean square
Leaf firing class	1	21.17
Lines	24	18.84**
Error	91	5.37

**Highly significant.

tions in the breeding nursery over a period of years have suggested the possibility that pollen of some lines is able to affect fertilization more readily than others when crosses with a given female parent are made. Data obtained in 1941 and presented in Table 4, although obtained from a small sample of each of 25 lines, tend to bear out this observation. The seed set produced by the pollen of individual lines used on the silks of Wf9×38–11 ranged from 12 to 89% of the receptive ovules available. Ample pollen was applied to the silks and it is felt that the observed differences in seed set are not due to deficiencies of viable pollen. Analysis of variance showed that the differences in seed set among lines were highly significant. There was no apparent relation between the resistance or susceptibility of the lines to leaf firing and the ability of their pollen to fertilize the ovules of Wf9×38–11. Differences between the two groups of lines, i.e., resistant and susceptible, to leaf firing were not expected, however, as the pollinations were made during a period of optimum temperatures.

The observations on drought-resistant strains reported by Jenkins (2), Sayre (6), and Jugenheimer (4) and the work of Heyne and Brunson (1) show that drought resistance is definitely inherited and indicate the possible achievements in breeding for drought resistance. Moreover, the observations reported in this paper further indicate that breeding for drought resistance can materially assist in lessening hazards to yield caused by incomplete pollination during drought periods.

SUMMARY

Factors affecting seed setting in corn were studied during the summers of 1940 and 1941.

Significant negative correlations were obtained between high temperatures and seed setting on inbred lines when self-pollinated. Some lines set seed well at the highest recorded temperatures while others set few seeds at relatively optimum temperatures. As an average of 2 years, seed setting ranged from 65 to 8% when the maximum temperature on the day of pollination ranged from 80° to 110° F, respectively.

Maximum seed setting was obtained when silks were exposed to pollen 2 days after emergence, and it declined rapidly thereafter for each additional 2-day period that pollen was withheld from the silks. Lines resistant to leaf firing, as well as the single crosses among them, set more seed throughout the life of the silks and remained receptive longer than did the susceptible lines and crosses. Loss of receptivity was more rapid in the inbred lines than in the single crosses.

Adequate soil moisture provided by irrigation, together with the associated lower temperatures and higher humidity, was effective in prolonging silk receptivity.

Highly significant positive correlations were obtained between rate of silk emergence and percentage of seed set for successive 2-day intervals following initial silk emergence. Lines and hybrids whose silks remain receptive for longer periods have a specific advantage under drought conditions.

Pollen of 25 lines placed the same day on randomly selected silks of the single cross Wf9×38–11 gave highly significant differences in resulting seed set. The differences obtained are thought to be due to varying degrees of cross-incompatibility existing between the pollen of various lines and the silks of the seed parent.

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SELECTION IN SELF-POLLINATED LINES OF *BROMUS INERMIS* LEYSS., *FESTUCA ELATIOR* L., AND *DACTYLIS GLOMERATA* L.[1]

H. K. HAYES AND A. R. SCHMID[2]

THE breeding of grasses in Minnesota was initiated in the spring of 1936. Native and introduced species and varieties of cultivated grasses were grown at the central and branch experiment stations alone and in various combinations with other grasses and legumes, and harvested as hay or clipped to simulate pasture, in order to learn what species and varieties were of greatest promise in Minnesota. No recently introduced species or varieties that were studied appeared as desirable as the cultivated grasses grown previously. It was decided, therefore, to confine the breeding studies largely to smooth brome, *Bromus inermis* Leyss., meadow fescue, *Festuca elatior* L., orchard grass, *Dactylis glomerata* L., crested wheatgrass, *Agropyron cristatum* (L) Beauv., and Kentucky bluegrass, *Poa pratensis* L. Previous studies by Schultz (4) with orchard grass and Murphy (1)[3] with crested wheatgrass and reviews of literature have been published. Myers (2,3) summarized briefly the literature relating to self- and cross-fertility in grasses.

The breeding studies have been organized under two main divisions. One method used with several grasses may be outlined briefly as follows: A nursery of several hundred spaced plants for each species worked with is studied for at least two seasons and from 80 to 100 plants of greatest promise are selected. During this period notes on individual plants are taken on plant habit, disease reaction, and yield. Clonal progenies of the first plants selected are studied in replicated rows or beds and about 20 of the clonal lines that have the best record of performance are selected. Open-pollinated seed is obtained from these selected clones by cutting all other clones in the trial before pollination. The seed of the clones selected is mixed and increased in an isolated seed plot. This seed furnishes the basis for a second cycle of selection and the desirability of the new strain is determined by field trials at the central and branch stations. Individual plant nurseries from such seed increases were started in 1942 and the performance studies in field plots were sown in the spring of 1943.

Another phase of the breeding studies has consisted of selection in self-pollinated lines of the same origin as the plants selected for clonal trials. There is a wide difference of opinion among grass breeders regarding the desirability of this method. To prove at all feasible it is essential that seed production under self-pollination conditions be sufficiently good to furnish the necessary material for selection. The selfed lines must be sufficiently vigorous so that they may be handled conveniently and for a sufficient number of generations in order to

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[3]Figures in parenthesis refer to "Literature Cited", p. 943.

make it possible to select for specific characters. With crested wheatgrass (1) seed setting under a bag was so low that selection in selfed lines did not seem practical, while with orchard grass (4) seed setting under conditions of self pollination was relatively good.

The present paper includes a study of the effects of self fertilization and selection with smooth brome, meadow fescue, and orchard grass. Studies of F_1 crosses will be reported also for brome grass and for orchard grass.

MATERIALS AND METHODS

Data were taken mainly on individual plants that were grown in the field, with sufficient space between plants to maintain their identity, from seedling progenies started in flats in the greenhouse during early spring. The second season's growth was used in most of the studies.

Only plants that appeared to excel in the characters considered to be of greatest importance were selected for self pollination. The characters studied included vigor, habit of growth, resistance to disease, and winter injury. Vegetable parchment bags, 18 by 3 by 2½ inches, were used to cover the panicles. They were tied to supporting stakes by string inserted in an eyelet in the base of the bag. Usually, five panicles per plant were enclosed, the stems being covered with cotton, the bag tied over the stems and also to the stake. Bags were examined as seemed necessary, particularly after a severe storm, and those that showed serious injury to the stems were discarded.

One- and two-year selfed progenies, S_1 and S_2, and a check from commercial seed were used to study the effects of controlled pollination and selection with brome grass and meadow fescue. A limited study of F_1 crosses was made in the brome grass. With orchard grass studies were made of F_1 crosses in comparison with S_1 to S_4 selfed lines. Two replications in randomized blocks, with from 12 to 20 spaced plants per row plot, were used in the studies. Data were taken on the plot basis at approximately the hay cutting stage for average total dry weight per plant for one or two cuttings.

Leaf spot reaction in brome grass caused primarily by *Selenophoma bromigena* (Sacc.) (Sprague and Johnson) was studied, each plant being placed in one of the classes 1 to 5, ranging from light to very heavy infection. Winter injury was studied in orchard grass and in meadow fescue by placing individual plants in one of five classes, class 1 with no winter injury and classes 2 to 5 representing a range from slight winter injury to complete winterkilling, respectively.

When insufficient seedlings were available for replicated plots, the progenies with a smaller number of plants were arranged systematically and check rows from commercial seed were grown nearby. Progenies with 10 or more plants per row plot have been used to increase the number of progenies studied. Means for such progenies, however, are less accurate than for the replicated studies.

Seed setting was determined by threshing the plants individually. It was difficult with this material to estimate seed production at all accurately by inspection. Consequently, a measured portion of the threshed and cleaned head material was taken, seedling production determined in a germinator, and the seedlings counted. Open-pollinated heads were handled in a similar manner, seed production being expressed as F over I, where F is the number of seedlings from open pollination and I represents seedlings obtained from selfed seed of the same plants.

Analyses of variance were calculated for the replicated trials for average

total yield of dry matter per plant, reaction to leaf spot, and winter injury, and the standard deviation of a difference between two means was calculated. Highly significant differences were obtained between lines for yield with each of the three species, for leaf spot reaction in brome grass, and for winter injury in meadow fescue and orchard grass. The results are given in frequency tables for the means of inbred lines and crosses using classes of plus and minus 1, 2, 3, etc., times the standard error of a difference from the mean of the commercial check. Average values for yield and other characters for the inbred lines and F_1 crosses are given in percentage of the commercial check as 100 computed by averaging the actual means for the lines of similar treatment.

EXPERIMENTAL RESULTS

A summary of seed setting under a bag for plants grown from commercial seed and from inbred lines for three species of grasses and from F_1 crosses in orchard grass is given in Table 1.

TABLE 1.—*Seed setting studies under bag isolation in Bromus inermis, Festuca elatior, and Dactylis glomerata.*

Material	Year	Number of plants		Mean F/I
		With seeds	Without seeds	
Bromus inermis				
Commercial	1937	45	2	126.7
Commercial	1939*	58	8	15.8
Commercial	1939	33	35	51.1
Commercial	1940	5	1	18.2
Commercial	1942	2	7	41.0
S_1	1940	23	67	18.5
S_1	1942	35	23	17.9
S_2	1942	21	22	20.1
Festuca elatior				
Commercial	1940	19	2	10.2
Commercial	1942	30	1	7.4
S_1	1940	155	66	16.0
S_2	1942	103	23	14.0
Dactylis glomerata				
Commercial	1942	13	5	25.9
F_1	1942	88	33	29.0
S_1 and S_2	1942	20	6	41.8
S_3 and S_4	1942	35	7	19.4

*Data from the Waseca Branch Experiment Station. Other data from University Farm, St. Paul.

During the years which include 1937, 1939, 1940, and 1942 for brome grass, there was a wide range in seed setting under a bag as shown by mean values of F over I ranging from 15.8 to 126.7. Plants of brome grass with average values of F over I of 50 usually set sufficient seed for selection purposes. The same clonal lines of brome grass were selfed at University Farm in 1937 and in 1939 and at Waseca in 1939. No apparent relation existed for seed setting of

clonal lines when only a single bag was used at each location and year for each clonal line. At Waseca in 1939, 8 bagged plants out of 64 produced no seed, while at University Farm for the same year 35 out of 68 produced no seed. Less than half the plants in S_1 and S_2 lines produced seed under a bag. In these years it would be correct to conclude with brome grass that somewhat less than half of the bagged plants produced sufficient seed to furnish material for selection in self-pollinated lines. In 1941 seed setting under bag isolation with several grasses including brome and meadow fescue was almost a complete failure.

During 1937, plants of meadow fescue from commercial seed of three different origins were selfed. Sixty-one plants, with 10 panicles per plant enclosed in a bag, produced 20 or more seeds ranging to several hundred, 31 plants produced less than 20 seeds per plant, all 92 selfed plants producing some seed. Data for 1937 are not summarized in the table as no comparisons for open-pollinated panicles are available. Data in 1940 and 1942 from S_1 and S_2 lines lead to the conclusion that seed setting under a bag in meadow fescue was somewhat better for plants from commercial seed than for relatively vigorous plants in S_1 and S_2 lines. Seed setting under a bag with meadow fescue was considerably higher, on the average, than for brome and somewhat higher than for orchard grass.

Previous data have been given by Schultz for seed setting in bagged orchard grass at University Farm, St. Paul, and Myers has shown conclusively that inherited differences in seed setting between inbred lines are present in orchard grass. The bagged plants of F_1 crosses in 1942, given in Table 1, did not set seed as well, on the average, as plants of inbred lines that had been selfed for either three or four generations. Seed setting in orchard grass under a bag has been sufficiently good at University Farm, St. Paul, so that it has proved relatively easy to obtain sufficient selfed seed for practical purposes.

Data are given in Tables 2 and 3, respectively, for yield and leaf spot reaction in brome grass. As was explained above, the effects of selfing were studied in randomized blocks of 12 to 20 plants per plot with two replications when sufficient seedlings were available. Data are presented also for systematic trials of single plot comparisons when 10 or more plants per line were grown. Most of the data in Tables 2 and 3 are from trials made the second season after the plots were established. Data are given for the first cutting only during the third season after the plots were established for 20 S_1 lines.

The total yield of two cuttings for 11 S_2 inbreds was 100.2 in terms of the commercial check as 100. Seven S_2 inbreds in single plot trials gave an average yield of 118.6%. The first cutting of 20 S_1 selfed lines averaged 92.6% in yield. The selfed lines differed widely in yielding ability. They yielded as well, on the average, as the commercial check. Most of the selfed material originated from an old pasture in Martin County, Minnesota, and the commercial check is from Canadian-grown seed. It is somewhat surprising that the selfed material yielded so well. The lines were much more uniform in growth habit than the check.

For leaf spot reaction the individual plants were placed in five

TABLE 2.—*Frequency distribution for average yield of two cuttings of selfed lines of creeping brome in yield classes of + or −1, 2, 3, etc., times the S.E.$_{diff.}$ from the yield of the commercial variety, 1942.*

Type of test	Material	Yield classes								Average yield in % of check as 100
		−3	−2	−1	0	+1	+2	+3	+5	
Replicated	S_1	–	1	1	–	–	1	–	–	95.3
	S_2	1	4	1	1	1	–	2	1	100.2
Systematic	S_2	–	–	1	2	–	2	2	–	118.6
	commercial	–	–	1	1	1	–	–	–	100.0
Replicated*	S_1	–	4	6	4	6	–	–	–	92.6

*1st cutting only.

TABLE 3.—*Frequency distribution for mean leaf spot reaction of selfed lines in creeping brome in classes of plus or minus 1, 2, 3, etc., times the S.E.$_{diff.}$ from the leaf spot reaction of the commercial variety, 1942.*

Type of test	Material	Leaf spot reaction classes									Average in % of check as 100
		−5	−4	−3	−2	−1	0	1	2	3	
Replicated	S_1						1		2		111.5
	S_2	3	2	1	1	1	1	1	1		74.6
Systematic	S_2		2	1		2	1	1			82.8
	commercial						3				100.0
Replicated*	S_1				6	2	9	1	1	1	94.8

*1st cutting only.

classes, as has been explained. The S.E.$_{diff.}$ between two means was 0.3. Highly significant differences were obtained in leaf spot reaction. S_2 selfed lines gave a mean value of 74.6% in comparison with the check as 100, showing that they were, on the average, rather resistant to injury by leaf spot. Selection in self-pollinated lines appears to be a desirable method of producing a resistant variety.

Previous studies by Tsiang (5) with brome grass, using selfed lines that were obtained from the studies reported in this paper, proved very conclusively that reaction to leaf spot was an inherited character. Tsiang also gave evidence for wide differences between selfed lines in beta-carotene content, yield, and other characters of agronomic importance. Crosses were made by Tsiang between individual plants of different S_1 lines. These were grown in comparison with clonal increases of the parent plants. The results for yield and leaf spot reaction are given in Table 4.

Two replications of clonal lines of SB 2, 3, 5, 6, 7, 8, 9, and 10 were grown but only single plots were grown of the F_1 crosses and selfed progenies of SB 2 and 6. The clonal lines gave yields ranging from 81.7 to 130 in terms of the check as 100 while the F_1 crosses ranged from 126.5 to 220.9. The number of plants available is too small to

TABLE 4.—*Comparison of clonally propagated one-year selfed lines of creeping brome and their F_1 crosses for yield and leaf spot reaction in percentage of the yield and leaf spot reaction of the commercial variety as 100.*

Selfed line or cross	In percentage of commercial variety as 100		Average number of plants per plot
	Yield	Leaf spot	
SB_2	103.5	85.7	6
SB_3	113.5	78.6	8
$SB_2 \times 3$	197.0	71.4	3
$SB_3 \times 2$	150.1	114.3	7
SB_2	103.5	85.7	6
SB_8	91.0	39.3	7
$SB_2 \times 8$	126.5	100.0	4
SB_5	81.7	89.3	5
SB_7	122.9	139.3	7
$SB_5 \times 7$	158.0	121.4	7
$SB_7 \times 5$	167.3	117.9	4
SB_5	81.7	89.3	5
SB_8	91.0	39.3	7
$SB_5 \times 8$	142.0	121.4	5
SB_7	122.9	139.3	7
SB_8	91.0	39.3	7
$SB_7 \times 8$	176.4	107.1	32
$SB_8 \times 7$	186.9	75.0	9
SB_9	130.0	82.1	8
SB_{10}	125.9	89.3	8
$SB_9 \times 10$	220.9	85.7	7
SB_6	131.7	53.6	6
SB_6–1	121.7	85.7	5
SB_2	103.5	85.7	6
SB_2–1	135.6	103.6	7
Commercial	100	100	16

draw definite conclusions regarding the mode of inheritance of leaf spot reaction. Reciprocal crosses of SB_2 and 3, two resistant clones, gave widely different results. In the cross $SB_9 \times 10$ the parent clones and F_1 progeny were resistant. Incidentally, this is the highest yielding F_1 cross. Several crosses were as susceptible, or more so, than the susceptible parent. Two second generation inbreds averaged higher in leaf spot infection than their parental clones. It is probable that leaf spot infection may have been due to several different causal organisms in these studies.

S_2 inbred lines of meadow fescue were grown in randomized blocks with two replications. Group 1 was tested in 20 plant plots and group 2 in 12 plant plots with a commercial check grown in each group. Data on average yield and average winter injury for these 49 S_2 lines are given in Tables 5 and 6.

TABLE 5.—*Frequency distribution for mean yield of S_2 lines of meadow fescue in yield classes of plus and minus 1, 2, 3, etc., times the S.E.$_{diff.}$ from the yield of the commercial variety.*

Type of test	Material	Yield classes							Average yield in percentage of check as 100
		−5	−4	−3	−2	−1	0	+1	
Group 1, 20-plant plots	S_2		3	7	8	6		1	63.6
Group 2, 12-plant plots	S_2	3	4	8	6	3			45.7

TABLE 6.—*Frequency distribution for average winter injury of S_2 lines of meadow fescue in classes of plus or minus 1, 2, 3, etc., times the S. E.$_{diff.}$ from the commercial variety.*

Type of test	Material	Winter injury classes					Average winter injury in percentage of check as 100
		0	+1	+2	+3	+6	
Group 1.........	S_2	10	5	3	6	1	154.0
Group 2.........	S_2	6	8	7	3		194.4

Data were averaged for each selfed line and the commercial check on the basis of the number of plants that were alive the previous fall. Consequently, those lines with the more severe winter injury yielded much less than the check which gave an average mean for winter injury of 1.2. Of the 49 S_2 lines that were compared with the check, from commercial northern grown seed, one S_2 line yielded somewhat more than the check and this same line in S_1 trials exceeded the check in yield. Nine other inbred lines yielded nearly as well as the check. Group 1 gave an average yield of 63.6 in terms of 100 as the check, while group 2 yielded 45.7% as much as the check.

The individual plants were placed as has been explained in five classes for winter injury, ranging from 1 with no injury to 5 for complete killing. The calculated standard errors of a difference for winter injury were 0.56 and 0.48, respectively, for groups 1 and 2. Sixteen of the S_2 lines were highly winterhardy in these studies. It is possible with this material that the reduction in vigor that was obtained as a result of selfing may have been responsible in part for the greater winter injury of many of the selfed lines than for the commercial check.

Studies with orchard grass consisted of a relatively small number of selfed lines, 39 F_1 crosses and a commercial check. Data were taken, as in meadow fescue, on the basis of plants alive the previous fall. The F_1 crosses were produced in this case by growing two clonal S_1 lines together, for each cross, in an isolated plot. In several cases the F_1 crosses were compared directly with S_2 inbreds obtained by selfing the clonal S_1 parents. The plants of each F_1 cross were uniformly alike and it seemed probable that most of the seed produced in these crossing plots was from cross pollination. Data are given on yield and winter injury in Tables 7 and 8.

TABLE 7.—*Frequency distribution for mean yield of selfed lines and F_1 crosses of orchard grass in classes of plus or minus 1, 2, 3, etc., times the S.E.$_{diff.}$ from the yield of the commercial variety, 1942.*

Type of test	Source	Yield classes								Average yield in percentage of check as 100
		−4	−3	−2	−1	0	+1	+2	+3	
Group 1	S_2	–	1	–	1	2	–	–	–	67.5
	S_3	–	1		2	2	–	–	–	66.2
	S_4	–	–	–	1	3	–	–	–	90.8
	F_1	–	–	–	1	2	6	4	1	132.9
Group 2	S_3	1	–	1	–	–	–	–	–	53.9
	F_1	1	1	2	5	9	7	–	–	94.9

TABLE 8.—*Frequency distribution for average winter injury of selfed lines and F_1 crosses of orchard grass in classes of plus and minus 1, 2, 3, etc., times the S.E.$_{diff.}$ from the commercial variety, 1942.*

Type of test	Source	Winter injury classes							Mean winter injury in percentage of check as 100
		−3	−2	−1	0	+1	+2	+3	
Group 1	S_2	–	1	–	1	1	–	1	108.1
	S_3	–	2	1	–	–	1	1	97.4
	S_4	2	2	–	–	–	–	–	56.5
	F_1	8	4	1	1	–	–	–	59.2
Group 2	S_3	–	–	–	1	–	1	–	121.4
	F_1	–	8	11	3	1	2	–	79.6

In group 1 four S_2 lines yielded 67.5% of the commercial check, five S_3 lines 66.2%, and four S_4 lines 90.8% of the check. Fourteen F_1 crosses gave an average yield of 132.9% of the check. In group 2 there were two S_3 lines, 25 F_1 crosses, and the check. The two S_3 lines yielded 53.9% as much as the check, while the 25 F_1 crosses yielded 94.9% of the check, on the average.

Several of the 3- and 4-year selfed lines in group 1 were less severely winter injured than the check. The average winter injury of four S_4 lines was 56.5% and of 14 F_1 lines was 59.2%. The 25 F_1 lines in group 2 were less severely injured on the average than the check.

DISCUSSION

Self pollination and selection have been carried on with several species of grasses during five different seasons. Seed setting under bag isolation was somewhat greater for meadow fescue than for orchard or brome grass. Nearly complete failure to obtain selfed seed was obtained in one year only when brome and meadow fescue were studied. During the remaining four years, sufficient selfed seed was obtained relatively easily with *Bromus inermis*, *Festuca elatior*, and *Dactylis glomerata* to make selection in selfed lines feasible, providing

it proves to be worthwhile as one phase of the breeding program. In order to have a fair chance of success two or three times as many plants should be selfed as will be needed. With the material available in these studies there has been little or no difficulty of selecting several plants in promising selfed lines that appeared equally desirable in the characters for which selection was practiced.

The relative value of selection in selfed lines, as a tool for the isolation of desired combinations of characters, can be determined only in comparison with other methods of selection. The ultimate proof of a breeding method is its value in the breeding of improved varieties. It seems probable that the isolation of clonal and selfed lines, their test for combining ability, and their combination in crosses to produce a synthetic variety, or to produce single or double crossed seed as has been outlined by Tysdal, *et al.* (6) for alfalfa, will prove valuable also in grasses.

There would seem to be a real opportunity to achieve marked improvement in forage grasses by several methods of selection. The necessary genetic diversity can be obtained eventually by the interchange of material between breeders who are working on the problem of improvement of the same species. Selection in selfed lines practiced for only a few generations seems a logical and efficient method of isolating relatively vigorous lines with the extent of homozygosity in important characters that is desirable.

SUMMARY

1. A considerable amount of selfed seed by bag isolation was obtained during four out of five years with brome grass, meadow fescue, and orchard grass. In order to obtain sufficient seed for selection it was necessary to bag about three times as many plants as could readily be used as parents for the production of selfed lines.

2. Plants of good vigor were selected for selfing. After two years or more of selection in selfed lines a few lines in each of the three species were obtained that were as vigorous as the commercial check.

3. From replicated studies in randomized blocks it was concluded that the selfed lines differed significantly in yield in all three species for reaction to leaf spot in brome grass and for winter injury in orchard grass and meadow fescue.

4. Eleven S_2 lines of brome grass in replicated trials yielded about the same, on the average, as the commercial check and about half of these were significantly lower than the commercial variety in leaf spot reaction. From studies of a few plants in each of several crosses between S_1 clones, the yield of F_1 crosses ranged from 126.5% of the commercial check to 220.9%.

5. Approximately 20 out of 49 S_2 lines of meadow fescue were significantly more severely injured by winterkilling than the commercial check. One inbred line yielded somewhat more than the check during both the S_1 and S_2 generations. The average yield of the 49 inbreds was 54.7% of the check.

6. Several 2- to 4-year selfed lines of orchard grass were as vigorous as the commercial check, although selfing on the average for 2 to

4 years led to a reduction in vigor. The 49 F_1 crosses gave about the same yield as the commercial check. There was a significant difference between selfed lines and between F_1 crosses in both yield and winter injury.

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VARIATION IN TANNIN CONTENT OF CLONAL AND OPEN-POLLINATED LINES OF PERENNIAL LESPEDEZA[1]

R. E. STITT[2]

SERICEA lespedeza, *Lespedeza cuneata* (Dum. de Cours) G. Don, a perennial species introduced from eastern Asia, has been found to be well adapted to the soil and climatic conditions of the southern United States. This species contains a considerable amount of tannin, a substance adversely affecting palatability. In order to plan a breeding program for the improvement of sericea lespedeza, it seemed desirable to study the variations of tannin within clones and individual plants from various seed sources.

The questions which this study has been designed to answer are twofold. First, are differences in the tannin content inherited? And second, can sufficient variation be found to warrant low-tannin selections being made? In the course of this study factors that may be correlated with the tannin content and may otherwise have selection value in an improvement program also have been determined.

REVIEW OF LITERATURE

The literature dealing with feeding trials of sericea lespedeza has been adequately reviewed by Clarke, *et al.* (3).[3] Both feeding and pasture trials have given variable or conflicting results. It is evident that some factor is often present which lowers the palatability, as judged by the intake of roughage and effect on the animal.

Clarke, *et al.* (3) identify the tannin in sericea lespedeza as belonging to the catechol group of tannins (2) from its reactions of an olive green color with iron-alum solution, a precipitate with bromine water, and being completely precipitated by formaldehyde in the presence of hydrochloric acid. They investigated

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[1]Cooperative investigations between the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering; the Hides, Tanning Materials, and Leather Division, Eastern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry, U. S. Dept. of Agriculture; and the North Carolina Department of Agriculture and the North Carolina Agricultural Experiment Station at Statesville, N. C. Part of a thesis presented to the faculty of the graduate school of the University of Minnesota, December 1941, in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with the approval of the Director of the North Carolina Agricultural Experiment Station as Paper No. 153 of the Journal Series. Received for publication January 21, 1943.

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[3]Figures in parenthesis refer to "Literature Cited", p. 954.

the tannin in the leaves and stems of sericea harvested at weekly intervals from May 29 to July 31, 1935, at Arlington Farm, Va. There was an increase from 7.5 to 18.0% of tannin in the leaves as the season progressed. The total tannin content of the stems was very low and varied from 1.0 to 1.6%. This variation in the stems was not correlated with the age of the plant.

The plants decreased in leafiness as the tannin content of the leaves increased. This created a balance whereby after the first of June the percentage of tannin in the whole plant was essentially constant. The percentage of tannin in the whole plant ranged from 6.1 on May 20 to 9.0 on June 20 and 8.0 on July 31. The dry matter in the fresh green plant increased progressively from 33.6 to 56.4 per cent.

Stitt and Clarke (5) made tannin analyses on samples of sericea lespedeza harvested at Statesville, N. C., at 14-day intervals from May 5 to October 20, 1936, from plots not previously harvested during the season. The tannin in the leaves increased from 6.3% on May 5 to 15.0% on June 30, after which there was a progressive decrease to 7.8% on October 6 and increase to 8.8% on October 20. The tannin in the stems varied from 1.8 to 2.9%. In general, the tannin content of the whole plant varied with that of the leaves.

Clarke, *et al.* (3) found that the results of precipitating the tannin with formaldehyde and hydrochloric acid differed from those of the hide-powder method by a constant factor and state, "under certain circumstances, therefore, this method might be used as a convenient procedure for determining the approximate tannin content of *Lespedeza sericea*."[4]

MATERIALS AND METHODS

The material used for the clonal study was selected from 83 different lots representing introductions from Asia and several selections made in the United States. The plants were grown in spaced plantings in the field. Six plants were selected in 1937 and increased by vegetative cuttings.

These clones were transplanted to the field in June 1938 and arranged in randomized blocks with five replications of each selection. Each plot consisted of 20 plants set 1 foot apart in a 4 × 5 foot rectangle. The outside plants of each plot were left as borders.

Five seed sources of perennial lespedeza, including introductions and selections made by the U. S. Dept. of Agriculture, also were chosen for study on the variability in tannin content and other characters between strains and individual plants.

Just prior to harvesting the plants of the selected clones and strains the height of each shoot was recorded in inches. The plants were cut 2 inches above the ground level, weighed immediately, and then air-dried in open paper bags in the shade. The leaves were separated from the stems for leafiness determinations and were then ground fine enough in a hammer mill to pass through a 1-mm screen.

Two methods of tannin analysis were used in the course of this study. The hide-powder method[5] of the American Leather Chemists Association, with modifications in procedure as outlined by Stitt and Clarke (5), was used in determin-

[4]*Lespedeza sericea* has been used in most of the literature for the species herein designated as *L. cuneata* according to the international rules of nomenclature. Sericea or sericea lespedeza is used as a common name.

[5]The hide-powder method determinations were made by the Hides, Tanning Materials, and Leather Division, Eastern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry, U. S. Dept. of Agriculture.

ing the tannin content of the clones. In order to compare methods, determinations on the clones and individual plants were made also by a precipitation method, using formaldehyde and hydrochloric acid to precipitate the tannin. This method saves one-half the time of the operator and can be used on smaller samples.

The total correlation of the methods was .61 which exceeds the 1% point. Analysis of variance revealed that the interaction between methods and clones was not significant, indicating that the two methods of analysis gave similar evaluations of the clonal tannin content.

EXPERIMENTAL RESULTS

STUDIES WITHIN AND BETWEEN CLONES

The mean squares from the analyses of variance of the total tannin, average height, number of shoots, leafiness, dry matter, and yield of the six *Lespedeza cuneata* clones are given by crops in Table 1. All of the characters measured showed highly significant differences between some of the clones with the exception of dry matter in the second crop. Block differences were significant for dry matter in the first crop and for tannin, height, dry matter, and yield in the second crop, showing that local control, in the form of randomized blocks, led to reduced error. These significant block differences indicate that soil variation has considerable effect on the development of sericea lespedeza. The relatively great variation in tannin between clones indicates that selection of clones from different seed sources should be very effective in isolating clones lower in tannin content.

TABLE 1.—*Mean squares from analyses of variance of data from Lespedeza cuneata clones.*

Variation due to	D. F.	Tannin	Height	Number of shoots	Leafiness	Dry matter	Yield
First Crop, May 25, 1939							
Blocks.....	4	0.90	1.26	6.64	0.48	3.66*	0.02
Clones.....	5	14.35**	80.18**	23.58**	125.47**	12.77**	0.559**
Error.......	20	0.60	2.10	3.72	2.85	1.19	0.017
Total......	29						
Second Crop, July 10, 1939							
Blocks......	4	4.42**	2.52*	21.87	1.79	3.83*	0.051**
Clones.....	5	6.76**	17.85**	138.07**	27.93**	2.56	0.079**
Error......	20†	0.37	0.63	17.13	3.05	1.29	0.006
Total......	29†						

*Exceeds the 5% point.
**Exceeds the 1% point.
†Three samples were lost during analysis and the tannin data interpolated. The degrees of freedom for tannin were 17 and 26 for error and total, respectively.

Percentage of total tannin in the leaves, height, number of shoots, leafiness, dry matter, and yield of the *Lespedeza cuneata* clones is given in Table 2.

TABLE 2.—*Total leaf tannin, height, number of shoots, leafiness, dry matter, and yield of Lespedeza cuneata clones.*

Clone No.	Total leaf tannin, %	Height, inches	Shoots per plant	Leafiness, %	Dry matter, %	Yield, tons per acre
			First Crop, May 25, 1939			
3–18	10.6	19.8	9.4	56.4	32.4	1.06
3–21	11.0	19.1	11.9	56.0	33.1	1.14
4–22	6.6	9.3	12.3	67.9	32.5	0.42
5–32	9.5	13.9	6.6	63.1	36.5	0.37
5–44	10.5	14.3	8.9	64.2	35.0	0.49
8–21	10.8	18.1	8.4	57.3	34.3	0.70
Average	9.9	15.8	9.6	60.9	34.0	0.70
Sig. dif. 5% point	1.0	1.9	2.5	2.2	1.4	0.17
1% point	1.4	2.6	3.5	3.0	2.0	0.24
			Second Crop, July 10, 1939			
3–18	12.2	15.1	22.5	67.3	38.5	0.85
3–21	11.5	13.5	26.4	68.3	38.9	0.80
4–22	10.4	10.2	33.0	73.0	39.5	0.69
5–32	13.2	14.9	20.3	69.0	40.4	0.67
5–44	13.5	13.0	30.9	71.4	40.1	0.75
8–21	12.9	11.7	21.4	72.4	39.8	0.49
Average	12.3	13.1	25.7	70.2	39.6	0.71
Sig. dif. 5% point	0.8	1.0	5.6	2.3	1.5	0.10
1% point	1.1	1.4	7.4	3.1	2.0	0.14
			Average of Two Crops			
3–18	11.4	17.4	15.9	61.8	35.5	0.96
3–21	11.3	16.3	19.1	62.1	36.0	0.97
4–22	8.4	9.7	22.6	70.4	36.0	0.55
5–32	11.3	14.4	13.4	66.4	38.4	0.52
5–44	12.0	13.7	19.9	67.8	37.6	0.62
8–21	11.8	14.9	14.9	64.9	37.0	0.60
Average	11.1	14.4	17.6	65.6	36.5	0.70
Sig. dif. 5% point	0.8	1.1	3.8	1.6	1.1	0.09
1% point	1.1	1.0	5.2	2.2	1.5	0.13

Each clone contained less tannin in the first than in the second crop. The differences were significant for all clones except 3–21. In the first crop, the leaves of clone 4–22 were significantly lower in tannin than the leaves of the other clones. Clone 5–32 was intermediate, and the other clones were high in leaf tannin.

The difference between clones was not the same in the two crops, however, clone 4–22 was the lowest in percentage of tannin for both

crops. Clone 3–21 was the highest in tannin in the first crop and next to the lowest in the second. Clone 5–32 was next to the lowest in the first crop and next to the highest in the second.

It is interesting to note that clone 4–22, with the lowest amount of tannin, was the leafiest clone in this test. Its yield, however, was low due to its lower height.

There were significant differences in height between the clones in both crops; however, they were not as pronounced in the second as in the first crop. On the basis of height, clones 3–18, 3–21, 5–44, and 8–21 had slower rates of growth in the second than in the first crop. Clones 4–22 and 5–32 grew relatively faster in the second crop. The average height of the first crop was 2.7 inches greater than that of the second.

In sericea lespedeza, the shoots of the first crop develop from crown buds located from just above the soil line to an inch or more beneath the surface. After the first growth of the season is removed, the subsequent growth is produced from buds near the ends of the stubble. Each of these stems usually produce several new shoots.

The shoots from crown buds have a greater diameter than the shoots forming the aftermath. This partly accounts for the greater proportion of stems in the first crop.

The average of the yields for the first and second crops were similar. The highest yielding clones in both crops were 3–18 and 3–21, and the lowest yielding were 4–22 and 5–32.

Correlation coefficients of the different characters were calculated from the analysis of covariance to determine the degree of association between clones for all characters studied. These were calculated separately for the two crops and for crop totals and are given in Table 3.

The tannin content of the clones increased with height in both crops. The first crop was taller than the second at the time of harvest and the tannin content was higher in the second than in the first crop, thus reversing the relationship of high tannin with tall plants which was evident within the crops. Clones 4–22 and 5–32 were slightly taller in the second than in the first crop, being exceptions to this relationship.

Tannin decreased as leafiness increased; however, the correlation was significant only in the first crop. The tannin-leafiness relationship was not independent of height. Leafiness decreased as height increased. This inverse relationship was due to an increase in the weight of the stems without a proportional leaf increase. Stem growth was largely in a longitudinal direction.

Clones 3–18 and 3–21 were vigorous and assurgent and very similar in habit of growth. Both recovered rapidly after the first crop was removed. Clone 8–21 was similar for the first growth period but made a slow recovery after the harvest. Based on general appearance and behaviour 5–32 and 5–44 can be placed in a second group with slow growth of the first crop followed by vigorous recovery. The growth of the shoots was spreading in both periods. Clone 4–22 was erect in habit and slow growing, with numerous shoots.

TABLE 3.—*Correlation of different characters between clones of Lespedeza cuneata.*

	Leaf tannin	Height	Shoots	Leafiness	Dry matter
		First Crop			
Height	0.89	—	—	—	—
Shoots	−0.37	−0.15	—	—	—
Leafiness	−0.82	−0.98	0.04	—	—
Dry matter	0.19	−0.17	−0.82	0.27	—
Yield	0.61	0.85	0.36	−0.90	−0.65
		Second Crop			
Height	0.97	—	—	—	—
Shoots	−0.49	−0.63	—	—	—
Leafiness	−0.14	−0.90	0.50	—	—
Dry matter	0.54	−0.15	−0.01	0.50	—
Yield	−0.22	0.49	0.27	−0.68	−0.59
		Crop Totals			
Height	0.77	—	—	—	—
Shoots	−0.64	−0.62	—	—	—
Leafiness	−0.59	−0.96	0.50	—	—
Dry matter	0.37	−0.14	−0.44	0.34	—
Yield	0.24	0.73	0.03	−0.83	−0.72

5% point for significance of r = 0.81; 1% point = 0.92.

STUDIES WITHIN AND BETWEEN STRAINS

The source of the seed of the five strains of perennial lespedeza chosen for study originally were introductions from Japan. All had been more or less selected since being introduced.

All of these strains represented open-pollinated seed. The amount of self- or cross-fertilization in lespedeza has not been studied carefully. It has been a general opinion of those working with lespedeza that there is a high percentage of self-pollination. The amount of variation that has been observed would indicate some cross-pollination. The writer has one procumbent line in which 14.6% of assurgent plants were obtained from the open-pollinated seed of one procumbent plant. The parent plant was surrounded by assurged plants. Selfed seed from this one plant produced all procumbent plants, indicating that foreign pollen was responsible for the assurgent plants.

The different lots of seed were planted in the greenhouse in January 1937 in rows 2 inches apart. The seedlings were transplanted to the field on August 11, 1937. They were set in plots containing four rows with 12 plants per row and spaced 1 foot apart each way. The plots were arranged in random blocks with five replications. The outside rows of each plot were treated as borders.

The individual plants of F. C. Nos. 19284, 12087, 04730, and F. P. I. No. 65903 (*Lespedeza cuneata*) were harvested for analysis on June 7 and of F. C. No. 19285 (*L. latissima*) on July 12, 1939.[6]

[6]F. C. and F. P. I. refer to numbers assigned, respectively, by the Divisions of Forage Crops and Diseases, and Plant Exploration and Introduction, both of the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture.

The tannin content of the leaf material from these strains was determined by the formaldehyde-precipitate method.

Mean squares from the analyses of variance for the five strains of the two perennial species of lespedeza are given in Table 4. There were highly significant differences between strains for all the measurements except yield and significant differences between strains for yield. A comparison of errors a and b indicates that there is more variation between strains than within strains.

TABLE 4.—*Mean squares from analyses of variance of formaldehyde-precipitate, height, number of shoots, leafiness, dry matter, and yield per plant for four strains of Lespedeza cuneata and one strain of L. latissima.*

Variation due to	D. F.	Formaldehyde-precipitate, %	Height	Number of shoots	Leafiness, %	Dry matter, %	Yield, tons per acre
Blocks ..	4	12.88	190.08*	138.83	228.09*	50.17	2.87
Strains..	4	901.77**	2741.77**	2520.63**	4227.74**	818.13**	3.54*
Error (a)	16	15.61	41.08	90.03	71.33	48.22	0.96
Plots....	24	—	—	—	—	—	—
Error (b)	464†	8.55	14.58	38.33	22.84	12.47	0.40
Total ...	488†	—	—	—	—	—	—

*Exceeds the 5% point.
**Exceeds the 1% point.
†11 degrees of freedom dropped because of missing plants.

The average measurements and their standard deviations of formaldehyde-precipitate, height, number of shoots, leafiness, dry matter, and yield for four strains of *Lespedeza cuneata* and one strain of *L. latissima* are given in Table 5.

There were significant differences in percentage of formaldehyde-precipitate in the leaves among each of the five strains, except F. C. 04730 and 19285. F. C. 19285 (*Lespedeza latissima*) was not harvested until a month later than the other strains and so may have changed in tannin content during the interim.

The strains showed considerable difference in type. The plants of F. C. 19285 were short, averaging only 8.9 inches even though harvested at a later date than the other strains. Plants of this strain produced a larger number of shoots than the others and were almost procumbent in habit. F. C. 12087 was the shortest of the assurgent strains. F. C. 19284, 04730, and F. P. I. 65903 were all tall growing. F. P. I. 65903 produced a relatively higher number of shoots than the other assurgent strains.

The extremely low tannin plants were non-vigorous. A large proportion of these plants showed signs of abnormal growth which may have been due to environmental factors such as injury during the process of transplanting from the greenhouse to the field or adverse soil conditions. In each strain there were a few plants lower in tannin and more vigorous than average. The plants of both of

TABLE 5.—*Means and standard deviation for formaldehyde-precipitate, height, number of shoots, leafiness, dry matter, and yield of four strains of Lespedeza cuneata and one strain of L. latissima.*

Strain No.	Formaldehyde-precipitate, %		Height in inches		Number of shoots per plant		Leafiness, %		Dry matter, %		Yield, tons per acre	
	Mean	S. D.	Mean	S. D.	Mean	S. D.	Mean	S. D.	Mean	S. D.	Mean	S. D.
04730*...........	16.9	3.65	19.8	4.61	12.1	5.40	60.5	6.08	38.8	3.65	1.01	0.69
12087*...........	14.3	3.69	15.2	4.70	12.7	5.02	67.6	4.88	38.2	5.24	0.87	0.72
19284*...........	16.6	2.37	22.2	4.22	10.9	4.44	57.9	4.80	37.8	3.88	1.02	0.61
19285†...........	22.4	2.01	8.9	1.88	22.5	8.29	74.5	3.55	44.4	2.90	0.94	0.54
65903*...........	18.6	2.46	19.4	2.93	18.8	6.93	63.6	4.02	37.7	1.67	1.36	0.57
Least significant difference at												
5% point.....	1.2		1.9		2.8		2.5		2.1		0.29	
1% point.....	1.6		2.6		3.9		3.5		2.9		0.40	

*Harvested June 7, 1939.
†Harvested July 12, 1939.

these low-tannin groups require further testing in order to determine their value.

The genetic relationship of F. C. 19285 to the other strains is not known. Morphologically it differs widely enough to have been given the species name *Lespedeza latissima* (Mats.) Nakai. Its growth was much shorter than the other strains, yet it was the highest in tannin content. This reversal from the positive height correlation found within strains may have been partly due to a progressive increase in tannin with season as F. C. 19285 was harvested 35 days later than the others.

Total correlations within strains between all possible combinations of the five different measurements are given in Table 6. Plants with a large number of shoots were taller than those with a small number of shoots. Leafiness decreased as height increased and so was also inversely correlated with number of shoots and yield.

Dry matter and yield correlations were negative and significant for all the strains. Thus, the higher the yield, the higher the moisture content. This tendency of the non-vigorous plants to be less succulent may have been due to stunting of some of the smaller plants. The leaves of these plants also showed more or less yellowing during the entire growing period.

The correlation coefficients between height, number of shoots, and yield with the formaldehyde-precipitate values are all positive and highly significant. The tannin content of the strains is associated with the general vigor of the plants.

The formaldehyde-precipitate values increased as leafiness decreased in strains F. C. 04730, 12087, and 19284. Dry matter and

TABLE 6.—*Correlation of different characters within strains of Lespedeza cuneata and L. latissima.*

	Strains				
	04730	12087	19284	19285	65903
Formaldehyde precipitate with					
Height	0.65	0.68	0.41	0.34	0.31
No. of shoots	0.65	0.45	0.48	0.22	0.08
Leafiness	−0.30	−0.69	−0.36	−0.16	−0.13
Dry matter	−0.40	−0.18	−0.56	−0.03	−0.08
Yield	0.60	0.58	0.53	0.25	0.33
Height with					
No. of shoots	0.62	0.43	0.43	0.45	0.26
Leafiness	−0.56	−0.80	−0.79	−0.55	−0.70
Dry matter	−0.34	−0.24	−0.14	−0.14	−0.33
Yield	0.81	0.81	0.70	0.84	0.72
No. of shoots with					
Leafiness	−0.46	−0.49	−0.41	−0.41	−0.38
Dry matter	−0.33	−0.07	−0.16	−0.29	−0.37
Yield	0.87	0.72	0.76	0.81	0.57
Leafiness with					
Dry matter	0.37	0.32	0.08	0.38	0.34
Yield	−0.57	−0.74	−0.63	−0.34	−0.47
Dry matter with					
Yield	−0.35	−0.25	−0.22	−0.24	−0.45

5% point for significance of r = 0.20; 1% point = 0.26.

formaldehyde-precipitate values were inversely correlated in F. C. 04730 and 19284.

Regression lines of height in inches and percentage of formaldehyde-precipitate are shown in Fig. 1. The differences among these regressions were tested by the method outlined by Snedecor (4) and gave an F value of 5.07, indicating highly significant differences. Thus, the rate of change in tannin per unit change in height was not the same for all strains.

From Fig. 1 it is evident that strains F. C. 04730 and 12087 were similar in rate of change in tannin per unit change in height. The differences among the regressions of strains F. C. 19284, 19285 and F. P. I. 65903 were tested and found to be nonsignificant. The strains thus fell into two groups for rate of change in tannin per unit change in height. The strains with the higher rate of change were more variable in both height and tannin content than those with the lower rate.

SUMMARY

1. Six clones of sericea lespedeza were studied at Statesville, N. C., for inherent differences in tannin content of the leaves, height, number of shoots, leafiness, dry matter, and yield as harvested on May 25 and July 10, 1939.

2. Relatively great variation in leaf tannin between clones was

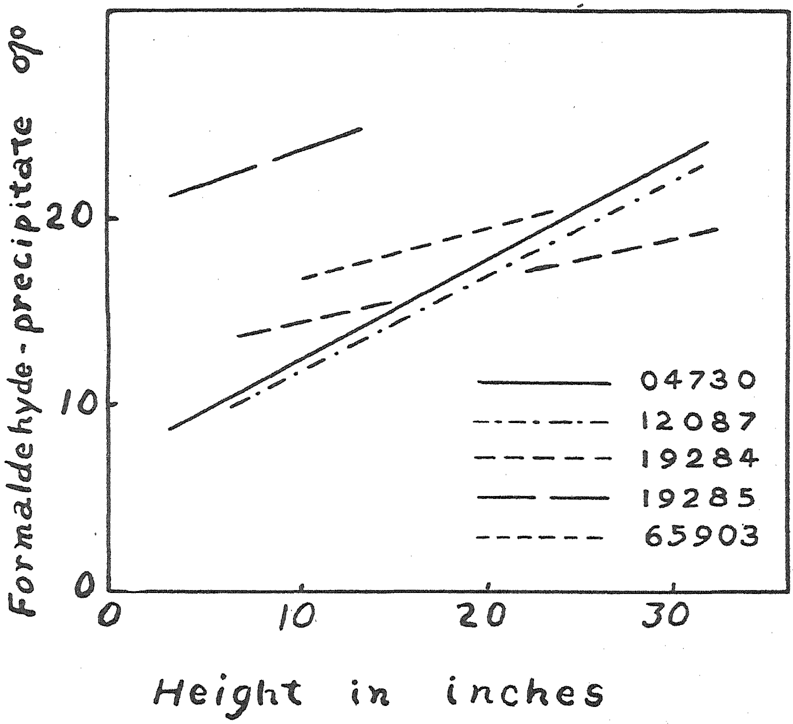

FIG. 1.—Regression lines of height in inches and percentage formaldehyde-precipitate of four strains of *Lespedeza cuneata* and one strain of *L. latissima*.

found, indicating that selection of clones from different seed sources should be very effective in isolating clones lower in tannin content.

3. One clone (4–22) was found to be inherently lower in percentage of tannin than the other clones, but probably not low enough to be of value for farm use. This clone was low in yield also.

4. The percentage of tannin in the clones was much higher in the second than in the first crop. The differences may have been due to a progressive seasonal increase. The type of growth was fundamentally different for the two crops. The second crop produced from two to three times as many shoots per plant as the first crop.

5. Inherent differences in type of growth were found. The six clones followed four patterns of growth, namely, vigorous and assurgent for both growth periods; assurgent with vigorous growth during the first period but slow recovery in the aftermath; and erect in habit with slow growth.

6. The tannin content of the clones increased with height. In the first crop tannin increased as leafiness decreased. Leafiness decreased as height increased in both the first and second crops as stem growth was largely in a longitudinal direction. Leafiness decreased as yield increased.

7. By use of a short method (formaldehyde-precipitate), the leaves of 100 plants of each of four strains of *Lespedeza cuneata* and one strain of *L. latissima* were analyzed for tannin. These plants were from open-pollinated seed.

8. Some of the strains contained a number of plants low in tannin. Tannin was directly related to height and yield in all strains and to number of shoots in four of the strains. An indirect association was present between tannin and leafiness in three strains and between tannin and dry matter in two strains.

9. As indicated by their standard deviations three of the five strains were lower in variability of tannin content than the other two.

10. The strains showed considerable difference in type. *Lespedeza latissima* (F. C. 19285) was relatively short and almost procumbent in habit. The *L. cuneata* strains varied in height but were all relatively tall and all assurgent.

11. From a study of the differences between the regressions of height on percentage formaldehyde-precipitate of the strains, it was found that the strains fell into two groups for rate of change in tannin per unit change in height.

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A CHART FOR EVALUATING AGRICULTURAL LIMESTONE[1]

C. J. SCHOLLENBERGER AND R. M. SALTER[2]

THE need of a simple method for evaluating agricultural limestone on a basis of probable activity and cost of lime active over different periods after incorporation into the soil has long been recognized. A plan for evaluation, suggested by the junior author, was published by Bear and Allen (2).[3] The basis is size composition data furnished by a complete sieve analysis. A ground limestone is considered to be made up of a number of size classes, as defined by standard sieves, of particles with known mean diameters (d) and similar average shape. Dissolution should act upon all particles alike in a given time, removing from each a shell of material uniform in thickness, and so reducing the diameters of all particles by a constant amount, a unit, up to the point of disappearance. The proportion (R) of the material in each size class which remains after the mean diameter (d) of all the particles in the size class has been reduced by a unit will be $R = \left(\frac{d - a}{d}\right)^3$. The proportion of the weight of each size class which has been active will be 1–R, a measure of the activity of the size class. The comparative value of any ground limestone of similar dissolution characteristics over the given time will then be the sum of the products, percentage of each size class in the limestone times a factor (1–R) appropriate to that size class and time.

The accuracy of an evaluation based on this idea depends primarily upon knowledge of the rate of attack upon limestone in a typical acid soil under field conditions. Upon this depends the value a, required for calculating 1–R. Obviously, a is not to be considered an absolute value, to be observed by direct measurements on limestone particles or by similar means. It is a calculated value which can be derived from data on disappearance of carbonate after an application at a known rate of a narrowly defined size class of limestone to a representative acid soil under conditions resembling those of practical liming. In an experiment of this kind, where the mean diameter of the limestone size class used is d and R is the fraction of the carbonate applied which remains after a certain time, $a = d\,(1 - \sqrt[3]{R})$. For such experiments to furnish a value of a which will be practically useful, it is important that the rate of application be adjusted to the soil's ability to decompose limestone, the so-called lime requirement. But since there would be required a time inconveniently long to approach satisfaction of the full lime requirement by medium or coarser size classes applied at practical rates, the aim in our experiments has been to apply limestone

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[3]Figures in parenthesis refer to "Literature Cited", p. 966.

as a median size class at moderate field rates, such that the lime requirement will be as nearly as possible half satisfied by the limestone decomposed at the end of the experimental period. These major experiments were supplemented by others on a smaller scale, applying coarser size classes of limestone at heavier and finer at lighter rates, as required by differences in particle diameters, to prove the point that under constant conditions the value of a is constant for particles of all size classes. Observations on the rates of activity at intervals during the comparatively short experimental periods were the basis of estimates of probable further activity over longer times.

PROCEDURE

Experiments to establish values for a have been conducted on six of the principal soil types of Ohio on which liming is important, at each location with separates, predominantly No. 50 to 70, from six commercial limestones widely used in Ohio. Duplicated frames 24 inches square and 8 inches deep were set in the ground and each filled with 200 pounds of the air-dried and screened soil previously removed, with which the weighed amount of the sized limestone had been thoroughly mixed at 2 to 4 tons to the acre rates. The soil in these frames exposed to natural conditions, uncultivated but with weeds allowed to grow, was sampled at intervals for 2 years and the carbonate remaining determined.

Data from eight or nine samplings from each of 12 frames for each limestone were thus obtained. The multiplicity of data permitted plotting and selection of probable values on a mathematical basis. The limestones ranged from a high calcium rock from Michigan to the nearly pure dolomite quarried at Woodville, Ohio, with four stones of intermediate magnesium contents and purities from other quarries in Ohio.

These experiments were supplemented by others in which small amounts of soil with the proper amounts of limestone separates of various size classes and varied nature, from approximately 50% purity to pure calcite and pure dolomite, were enclosed in cloth bags and buried to plow depth in the field for recovery intact after suitable times.

RESULTS

Values for a indicated by these experiments varied consistently, inversely with the ratio dolomite to calcite in the limestone and directly with time as expected from theoretical considerations, including the factor of diffusion through soil. The latter is the basis of extension to longer periods, 4 and 16 years, than were actually covered by the experiments. The 16-year period was selected as possibly approximating an extreme value for the length of the liming cycle. It is not to be inferred that this is necessarily the time an adequate liming may be expected to be economically effective. It was concluded from this work that the calcite and dolomite components of limestone vary in activity in the soil, but the content of earthy impurities has practically no influence except as a diluent reducing the total neutralizing power.

The initial activity of an impure limestone is not less than that of a pure limestone with similar ratio calcium to magnesium, of the same fineness, when applied to furnish the same total amounts of

calcium and magnesium carbonates. Dolomitic limestones are less active than high-calcium limestones of the same size composition, but the difference is important only with short time periods and coarse materials. With fine materials and over longer times, the generally higher total neutralizing powers of high-magnesium limestones may cause them to excel in activity high-calcium limestones otherwise similar.

The values for *a* shown in Table 1 were calculated from the experimental data. They are believed to be applicable under average conditions of liming soils in Ohio and the time periods considered are those of greatest practical importance. A table of values of 1—R was calculated therefrom for use as previously outlined. However, this method requires considerable further calculation as well as a detailed knowledge of the size composition of the material, not always available. An easier method of evaluation is desirable even at some sacrifice in accuracy. It may be pointed out that practical liming operations never result in the perfect distribution of limestone throughout the soil that must be assumed in evaluation, so a method of moderate precision should suffice.

TABLE 1.—*Values for a applicable under Ohio conditions.*

Kind of limestone	Three months inch	One year inch	Four years inch	Sixteen years inch
Calcitic..........	0.0022	0.0046	0.0069	0.0082
Dolomitic........	0.0011	0.0030	0.0055	0.0074

Observations on the size composition of commercial agricultural limestone grades, ranging from coarse screenings to superfine kiln-dried limestone, have shown a marked trend toward a similar pattern of size distribution in all these products. When plotted in the proper manner, percentages passing standard sieves vs. diameters of the size classes so defined, the points representing the great bulk of each grade tend to fall on or near straight lines. Two studies of size composition of all samples that could be secured from Ohio producers, respectively in 1932 (5) and 1941, have led to the same conclusion. So far as value as a soil neutralizer is concerned, the size composition of practically all commercial agricultural limestone can be represented with insignificant error by a simple visual estimate as a straight line on a chart. This fact makes possible the construction of an alinement chart to avoid most of the calculation required in evaluation. More important, it makes possible an evaluation from limited sieve data, even to the extent that knowledge of percentage passing but one sieve, e. g., No. 100, will probably be sufficient for practical purposes.

AN EVALUATION CHART

Fig. 1 is an evaluation chart for agricultural ground limestone designed for the graphical method of evaluation outlined. The horizontal spaces thereon represent U. S. standard sieves and are

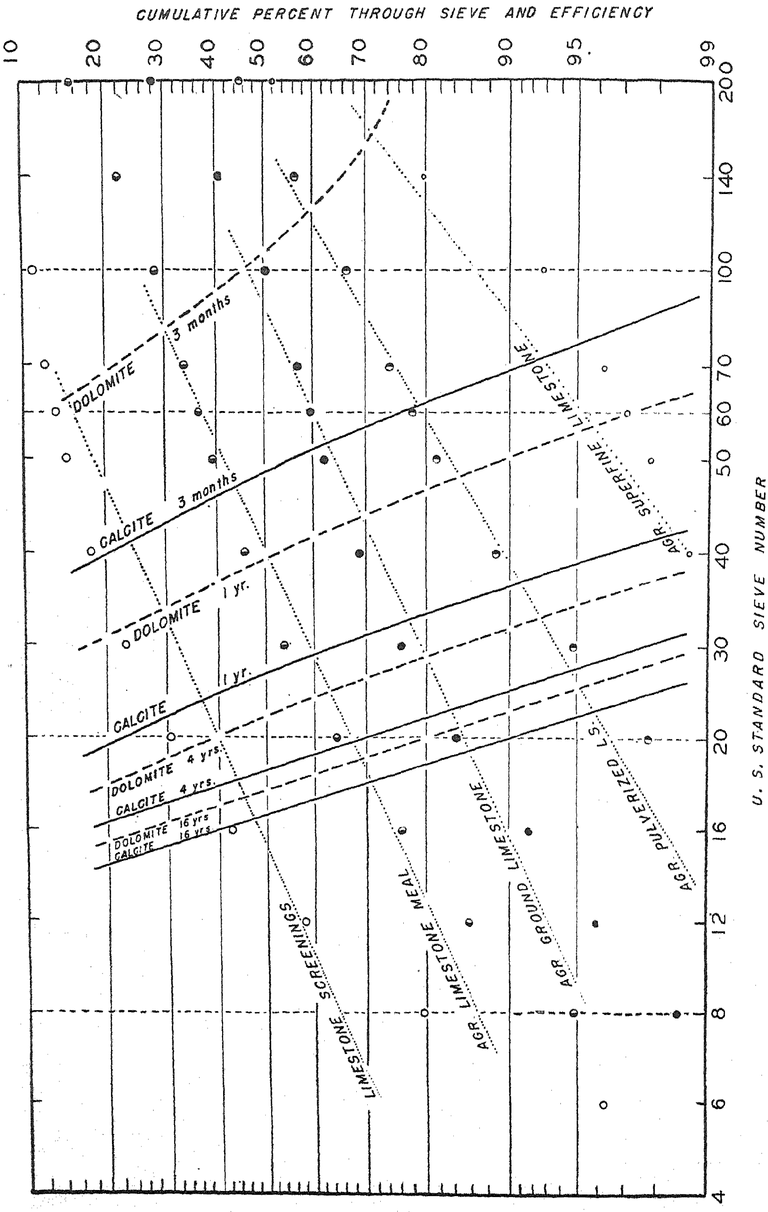

FIG. 1.—Evaluation chart for agricultural ground limestone.

numbered correspondingly at the bottom. These spaces are proportionate to the logarithms of the mesh diameters of successive sieves and, since the latter are in the constant ratio square root of 2, are equal. An exception is the No. 60 sieve which is included because it is specified by the Ohio liming materials law. The mesh diameter of this member of the double set of testing sieves is related to those of the successive sieves of the single set by the constant fourth root of 2, so it has a half space on the scale. This and the other sieves specified by the Ohio law are indicated by the vertical short dashed lines on the chart. The positions of other sieve lines are shown by short lines at the top and bottom of the chart, with the U. S. standard sieve numbers at the bottom.

Referring to the horizontal lines on the chart indicating divisions on the vertical axis of the plotting, the corresponding scale of percentages at the right side of the chart indicates both cumulative[4] or total percentages of the limestone passing the various sieves and the probable percentage efficiency or activity in soil neutralization of the material as a whole. The vertical spacing is on a probability scale, primarily to increase the tendency for the points representing size composition to fall on straight lines (1). Another advantage is that this scale, compressed at the middle and symmetrically expanded at the ends, automatically increases the precision of readings for the finer and more valuable grades of limestone. The omission of a 100% point from this scale is required by considerations of probability.

The heavy diagonal lines in the general direction upper left to lower right and marked "Calcite 16 years", etc., are the loci of solutions to problems of activity of pure limestones composed of a regular succession of particle sizes, conforming with the trend previously observed (5) in commercial limestone grades. The locations of these "efficiency lines" were determined in the following way. In the preliminary stages of developing the chart, with the system of coordinates described, it was observed that the straight lines taken for present purposes to represent average size compositions of the grades (further described in the next paragraph) tended to intersect at a point off the chart. From this point about 30 lines were drawn, well distributed over the chart, to represent imaginary grades of limestone with the regularity in size composition noted. The size composition of each such imaginary grade was read from the per-

[4]In making sieve analyses, the usual procedure is to determine separately the percentages held between sieves, each such percentage corresponding to a size class defined by the mesh diameters of the two sieves, one just passing and the other retaining that portion of the sample. These data are used in the arithmetical method of evaluation. But in plotting sieve analysis data, it is necessary to consider the total percentage of the sample which passes each sieve; this is called the cumulative percentage passing, because it is the sum of the percentage held between that and the next finer sieve plus the percentages found on all the finer sieves and the pan. It is the percentage that would pass if the sieve in question was the only one used in testing. Sieve analyses of agricultural limestone are required by the laws of Ohio and some other states to be stated in the cumulative form. For example, 95% passes sieve No. 8, 65% passes sieve No. 20, 35% passes sieve No. 60, and 28% passes sieve No. 100, is a statement in the required form.

centage values at intersections with the vertical sieve lines on the chart. From the size composition data so derived and the 1–R factors from *a* values previously established, the activities of a pure high calcium limestone and a pure dolomite were calculated, each for the four time periods considered. On each line representing an imaginary grade, the points where these calculated activities corresponded to the percentage scale were marked. The corresponding points of each set on all the lines were found to fall on a line or smooth curve, which were then drawn in and the hypothetical grade lines were finally erased from the chart. It will be noted that there are four pairs of efficiency lines, referring to the time periods 16 and 4 years, 1 year and 3 months. The solid line of each pair refers to calcitic and the dashed line to dolomitic limestones, as marked.

The diagonals of the second set, lightly dotted straight lines in the general direction lower left to upper right, are the "fineness lines" corresponding to average grades of commercial agricultural limestones on the Ohio market in 1941. The actual size composition of each average grade is shown by the points printed on the chart, those of each set distinctively marked. Efficiencies read from the percentage scale, corresponding to the intersections of average fineness lines with the efficiency lines, agree in all cases with those calculated from 1–R factors and the size compositions indicated by the respective sets of points, according to the arithmetical method previously outlined.

With this alinement chart it is possible to calculate graphically the probable activity of any ground limestone applied at practical rates to acid soils, provided the limestone does not depart too widely from average size composition characteristics. This condition will be met if the significant size composition points (those corresponding to important size classes occurring in the material) fall reasonably near a straight line when plotted on the chart, so that the fineness line can be fitted to these points without difficulty by visual estimation. A brief study of the relation of a similar average fineness line to the respective set of points, both as printed on the chart to show the average size characteristics of a representative grade of agricultural limestone, will develop judgment in this respect. All commercial and home ground agricultural limestones so far examined have shown sufficient regularity in size distribution for evaluation without great errors. In nearly all comparisons between graphical and arithmetical evaluation of actual samples, agreement was within 5%. In this use of the chart, the variables size composition and time are considered. The readings so secured may be further utilized to include in a simple manner chemical composition as a third variable.

USE OF CHART FOR AGRICULTURAL LIMESTONE EVALUATION

This chart may be used to estimate the activity or effective value of any ground limestone of known fineness and chemical composition at the end of a specified time after application to the soil, at a practical rate consistent with the soil's ability to decompose the amount of limestone applied. The idea of evaluation includes the

assumption of uniform incorporation to plow depth, to secure the best distribution possible with the fineness of the material, in a definitely acid soil under climatic and soil conditions similar to those in Ohio. It is believed that, with judgment, different materials may be compared and proportionate values assumed for shallower or surface applications under similar conditions. Effective value is stated as calcium carbonate equivalent (CCE), percentage of the weight of liming material applied.

1. Judge the general nature of the limestone from the ratio, total neutralizing power expressed as percentage calcium carbonate equivalent (TNP) divided by percentage magnesium (Mg), hereinafter indicated TNP/Mg.
   a. If TNP/Mg exceeds 50, consider the limestone to be calcite.
   b. If TNP/Mg is less than 10, consider it to be dolomite.
   c. If TNP/Mg ranges 10–50, consider the neutralizing values of both carbonate minerals in the limestone.
2. Plot the sieve data for the limestone on the chart, marking temporarily on each vertical line representing a sieve the total or cumulative percentage passing that sieve, according to the scale of percentages at the right side. Fit the "fineness line" to the point or points, with regard to the following:
   a. If only a single point is known (preferably for a fine sieve, for example, No. 100), the fineness line is defined by laying a transparent straightedge or stretched thread to pass through the point and have a slope consistent with that of the nearest of the fineness lines printed on the chart, representing average commercial limestone grades.
   b. If two or more points are known, not falling exactly on a line with the proper slope, most weight should be given points representing the finer and more active part of the material, as a rule. The fineness line in that event should fall on or between points representing finer sieves, and progressively farther from points representing coarser sieves, as the latter increase in coarseness, as may be required to give the line a proper slope. An exception to the foregoing may be materials predominantly coarse and very deficient in the fraction passing No. 100, for which percentage passing a coarser sieve, e. g., No. 12, may better indicate the average fineness. In such cases, the fineness line is given the slope normal to the coarser grade with a similar percentage passing the sieve in question. It should be noted that of points for coarse sieves, all representing high percentages passing, only the point for the finest of these sieves is significant.
   c. With a sufficient number of significant points in linear relation on the chart, the fineness line is defined without consideration of slope.
3. From the intersection of the fineness line with the calcite and /or dolomite efficiency line appropriate to the time to be considered, as printed on the chart, read the "efficiency" of calcite (*c*) and/or dolomite (*d*) as a percentage on the scale at the right.

4. Referring to the three cases considered in item 1, calculate the "activity" of the limestone as percent calcium carbonate equivalent (CCE) as follows:
   a. $c \times$ TNP/100 = activity of calcitic limestone.
   b. $d \times$ TNP/100 = activity of dolomitic limestone.
   c. For a limestone containing important amounts of both calcite and dolomite, first calculate the neutralizing powers of the component carbonate minerals, from the percentage magnesium (Mg) and total neutralizing power as percentage calcium carbonate equivalent (TNP):
      Mg $\times$ 8.23 = DNP, neutralizing power of dolomite in the limestone.
      TNP − DNP = CNP, neutralizing power of calcite in the limestone.
      ($c \times$ CNP/100) + ($d \times$ DNP/100) = activity of a magnesian limestone.
5. Analyses of agricultural limestone usually refer to air-dry or moisture-free material, whereas that shipped in bulk may contain up to 10% or more moisture. For a material with M % moisture, the activity calculated on the dry basis is multiplied by (100 − M)/100 to secure the activity of the material as purchased or applied to the land.

"Activity" is a comparable value which can be calculated for any limestone of known size and chemical composition, and for some other materials,[5] enabling comparison of values offered by various liming materials at different prices per ton applied to the field and over different time periods.

Example 1.—A dealer guarantees the following for his ground limestone:

Sieve analysis		Chemical analysis (dry basis)	
Pass No. 8	99%	Total neutralizing power (TNP)	101.8%
Pass No. 20	90%	Calcium (Ca)	23.4%
Pass No. 60	60%	Magnesium (Mg)	10.6%
Pass No. 100	50%	Moisture in fresh material, about	5.0%

He offers to spread this ground limestone on the field for \$4 a ton, or will spread high-magnesium hydrated lime, TNP 170, for \$12 a ton. Which should be the choice of a truck grower who is interested only in immediate effects and has been advised that his soil needs at least 2 tons calcium carbonate equivalent of quickly active lime to the acre to insure success with vegetables?

The analysis shows the ratio TNP/Mg to be 9.6, so this limestone may be evaluated as a dolomite. To plot the sieve analysis on the chart, temporary marks are made at 99% on the No. 8 sieve line, at 90% on the No. 20 line, at 60% on the No. 60 line, and at 50% on the No. 100 line. The points are seen to lie on a curve. Their general

[5]The activity of ground burned lime and hydrate is considered to be identical with total neutralizing power, irrespective of magnesium content and time. The chart is intended for the evaluation of raw limestone only.

position shows that this sample is a little finer than the average agricultural ground limestone. Laying a transparent straightedge on the chart and comparing the positions of the four points for this sample with the corresponding points representing the average for the grade Agricultural Ground Limestone, as printed on the chart, the position of the fineness line for this sample is decided.[6]

The fineness line for this sample, located as described, is noted to intersect the Three Months Dolomite efficiency line printed on the chart at 47%, which is our value *d*. Then, for $d \times$ TNP/100, we have $47 \times 1.018 = 48\%$ calcium carbonate equivalent (CCE) active lime supplied in 3 months. The correction for 5% moisture in the fresh material, multiplication by $(100 - 5)/100 = 0.95$, reduces the activity to 46% CCE. Therefore, to supply 2 tons CCE of lime active within 3 months, considered to be the minimum necessary, there must be applied $2/0.46 = 4.35$ tons of the ground limestone, costing $17.40. The same amount of active lime will be supplied by $2/1.70 = 1.18$ tons of the hydrate, costing $14.15. The hydrate offers the better value when immediate effect is the sole consideration.

But suppose that the grower anticipates the acute need for lime by applying it the previous year to the field he intends to put in vegetables. The fineness line then intersects the One Year Dolomite efficiency line at 72%, our new value for *d*. Applying the same corrections for composition, this becomes 70% CCE active lime supplied in 1 year. Two tons CCE of lime active the first year will be supplied by $2/0.70 = 2.85$ tons of the limestone, costing $11.40. The cost of the required amount of active lime in hydrate will be the same as before, $14.15, so the limestone offers the better value if applied a year in advance.

Example 2.—For the 1941 season, a dealer in Ohio offered liming materials delivered at nearby farms, with guarantees and prices per ton as noted below:

A. Coarse high-calcium limestone meal, 22% passes No. 100, TNP 95%, at $2.50 a ton.

B. Fine high-calcium limestone meal, 33% passes No. 100, TNP 95%, at $2.80 a ton.

C. High-calcium agricultural ground limestone, 55% passes No. 100, TNP 95%, at $3.50 a ton.

D. Pulverized kiln-dried dolomitic limestone in bags, 78% passes No. 100, TNP 107%, at $6.25 a ton.

E. High-calcium hydrated lime in bags, TNP 135%, at $10.50 a ton.

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[6]In this decision, most weight is attached to the pass No. 100 and pass No. 60 points, somewhat less to the pass No. 20 point, and little to the pass No. 8 point, since the latter represents so small a percentage not passing. Of the three significant points, that for the No. 20 sieve represents only 10% of the total material, so is given less weight. Of the two highly significant points remaining, since both represent fine material, the slope of the nearest average fineness line has considerable influence in deciding the best position for the fineness line of this sample. The fineness line decided upon will be duplicated if a straightedge is laid at 97.5 on the No. 8 line at the left and at 28 on the No. 200 line at the right edge of the chart.

F. High-magnesium hydrated lime in bags, TNP 175%, at $11.50 a ton.

What are the costs of active lime in these products, on 1 and 4 year bases?

This example is intended to illustrate the simplest possible use of the chart in solving a practical problem with only a minimum of data. Values estimated for the ground limestone products with the aid of the chart and for the hydrates by calculation only are shown in the tabular arrangement following:

Material	Estimated efficiencies and costs per ton CCE of active lime			
	In first year		In first four years	
	Efficiency	Cost	Efficiency	Cost
A	55	$5.14	63	$4.50
B	67	4.72	74	4.28
C	84	4.73	89	4.45
D	92	6.34	97	6.02
E	135*	7.77	135*	7.77
F	175*	6.57	175*	6.57

*Activity as percentage calcium carbonate equivalent.

For the high-calcium meals and ground limestone, all with the same guaranteed total neutralizing power, 95% calcium carbonate equivalent, efficiencies were estimated by laying the straightedge on the chart to pass through the points on the No. 100 sieve line corresponding to the guarantees, in each instance adjusting the slope to be consistent with those of the adjacent average fineness lines and reading values at the intersections with the One and Four Years Calcite efficiency lines. For the pulverized dolomitic limestone, values were read at the intersection of its fineness line with the corresponding dolomite efficiency lines. The total neutralizing power guarantees were taken into account, likewise probable moisture contents, in calculating costs per ton calcium carbonate equivalent of lime active in the times considered. There were no guarantees for moisture contents, but it was assumed that the bulk materials contained 7% moisture, the optimum for handling with an endgate spreader, and that the bagged materials were dry. For example, material C has TNP 95 and sells for $3.50 a ton. It is assumed to contain 7% moisture. The One Year Calcite efficiency was read 84%. The calculation is $\frac{\$3.50}{0.84 \times 0.95 \times 0.93} = \$4.73$, cost per ton CCE lime active in 1 year. For the hydrated limes, with activities not considered to increase with time and dependent upon TNP only, the chart is not used. For example, the calculation with the last is $\frac{\$11.50}{1.75} = \$6.57$, cost per ton CCE lime active in any time.

COMPARISON WITH EVALUATION BY OTHERS

Some simpler methods for agricultural limestone evaluation with sieve analysis data have been proposed. DeTurk (4) has published the "Illinois Limestone Score Card", a set of factors to be used with sieve analysis data and the products summed for a comparative value on the principle of our arithmetical method. No consideration is given differences in chemical composition or time. A study of values so indicated for average grades of limestone has revealed that this method as originally described furnishes comparative values corresponding closely to ours when there is assumed a very high value for a, according to our experimental data excessive in relation to economic time periods and rates of application. Doctor DeTurk has stated in a personal communication that in developing this method he had in mind only long time values, about 12 to 15 years. The tendency will therefore be to overvalue coarse grades over shorter times.[7]

Coleman and Klemme (3) have recently published a method in which the percentage of the material passing 12-mesh (No. 14) is taken as an index of comparative value. A regularity in size composition is thus assumed similar to that on which our chart is based. In fact, the data for average limestone grades sold in Missouri plot as practically straight lines of normal slope on the chart, only those for the finest grade showing much departure from a linear relation. In a personal communication, these authors state that their conclusions are based on a study of the size composition of agricultural limestones on the Missouri market and some data for rates of activity of limestone size classes published by the Pennsylvania station (6). The latter were based on experiments continued for two years, with no attempt to evaluate the time factor further. Any conclusions therefrom may be expected to be more applicable to short times than to long times of activity in the soil. A comparison of the values indicated for representative grades by the Missouri method and by our method shows good agreement when there is assumed a small value of a. In contrast with the Illinois method, the tendency will be to undervalue coarse materials over longer times. With both the Illinois and Missouri methods of evaluation, differences in chemical composition as well as the time factor are neglected.

SUMMARY

A chart for graphic evaluation of agricultural limestone is described and figured, with examples of use in solving practical problems. It may be read with practical accuracy if sufficient fundamental data

[7]In a recent publication from the Illinois station (Ann. Rpt., 51:35–37, 1942), the limestone score card factors are revised. Although the value assigned to the very coarsest particles, 4- to 6-mesh, is lowered to a point consistent with our evaluation of the 16-year efficiency of that size class, the values assigned to other coarse size classes are not, and all material passing 28-mesh (No. 30) is assumed to be of equal value, in contrast with the original assumption that the pass 100-mesh (No. 100) material shows maximum activity. The new plan for evaluation therefore favors coarse materials even more than does the old one.

are available, or for rough indications from very limited data, and in either case with facility after its use is understood. This is the first method to be published which takes into consideration all the variables, time, chemical and size composition, influencing the value of limestone as a soil neutralizer and source of active lime, and based on experiments simulating practical field conditions.

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INHERITANCE OF GREEN AND BROWN LINT IN UPLAND COTTON[1]

T. R. RICHMOND[2]

THE normal color of the lint of cultivated upland cotton, *Gossypium hirsutum* L., is white or creamy white. Upland cottons with several shades of brown lint and one or possibly two shades of green lint have been reported. These manifestations of lint color could be the results of recent mutations from the normal white, but as the cotton of antiquity is usually described as having colored fibers, the various colors in the lint may have been carried as mixtures in cultivated stocks for many years. This paper gives the results of genetic studies with three types of brown lint and a green lint cotton.

LITERATURE

According to Watt (11),[3] "All truly wild species have a red coloured woolly coating to the seed, which may or may not be referable to two layers, an inner, or fuzz, and an outer, or floss." He states also that, "the presence of a white fleece may accordingly be regarded as a condition brought about by cultivation."

Ware (8, 10) and Brown (2) have shown that the F_1 generation of a cross of Nankeen brown lint × white lint was intermediate in color and the F_2 segregated in ratio of 1 brown: 2 intermediate: 1 white. Ware (9) has reported on four strains of cotton carrying rust, dingy brown, yellowish brown, and green lint, respectively. Each type when crossed with its white allelomorph was "an intergrade between that of the respective colored parents and the white parent," and in the F_2 generation the crosses segregated into three classes in the ratio of 1 colored parental type: 2 intermediate: 1 white parental type.

MATERIALS AND METHODS

One inbred line of upland cotton with green lint and three inbred lines of brown lint cotton were used in this study. The records of the parentage of the green lint strain are not clear, but it is presumed to be a selection from an old stock known as Texas Green Lint. The brown lint strains, Nankeen, Texas Rust, and Higginbotham, were obtained from stocks at the Texas Agricultural Experiment Station. Nankeen lint is dark brown and when in homozygous condition gives a distinct contrast to the light brown or buff color of Texas Rust. The color of the lint of Higginbotham is only slightly lighter than that of Texas Rust, and until recently both were thought to be expressions of the same gene. Most of the material reported in this paper involves crosses of Texas Green Lint, Nankeen, and Texas Rust. Hutchinson and Silow (5) have given symbols for several genes which condition color in cotton lint, but as the stocks used in this study have not been checked with their types, symbols will not be assigned to our types until

[1]Contribution from the Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Department of Agriculture, in cooperation with the Texas Agricultural Experiment Station, College Station, Texas. Received for publication May 11, 1943.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 974.

this has been done. Our types will be referred to in the tables and elsewhere in the paper, when convenient, by an abbreviation of the names as follows:

Types with green lint:	
Texas Green Lint	TGL
Types with brown lint:	
Nankeen	Nan
Texas Rust	TR
Higginbotham	Hig
Types with white lint:	
White Lint	W

The X^2 method for the determination of the goodness of fit, as given by Fisher (4), was used in testing the monohybrid ratios. The dihybrid ratios were tested by Mather's (7) method of analysis of X^2 by orthogonal function.

EXPERIMENTAL RESULTS

GENETIC ANALYSIS

Segregating generations of crosses in the six possible combinations between Texas Green Lint, Nankeen, Texas Rust, and normal white lint lines were classified for lint color. The results are given in Table 1. With the exception of the TGL × Nan cross (Table 1, No. 7), progenies of each F_1 backcrossed to normal white were available for classification (Table 1, Nos. 2, 4, 6, 9, and 11). Texas Rust and Higginbotham were considered for several years to be the same genotype, but, as will be shown, the results of one backcross progeny indicates a difference in the genotype for lint color (Table 1, No. 13).

Crosses of TGL, Nan, and TR with white lint invariably have shown mono-hybrid inheritance with incomplete dominance (Table 1, Nos. 1, 3, and 5). The goodness of fit of the observed to the theoretical numbers when the data for each class of each family are combined is given as *deviation* χ^2 and the agreement among families in the type of segregation is given in terms of *heterogeneity* χ^2. In these crosses the respective probability values show no significant deviation from theoretical expectations. These findings are in agreement with those of Harland (6), Ware (9), and others who have studied crosses of these or similar stocks.

The segregating progenies of crosses of TGL×Nan and TGL×TR were separated into four classes designated as brown-green, brown, green, and white (Table 1, Nos. 7 and 8). A two-factor type of segregation was clearly indicated. Both F_2 progenies fit a 9:3:3:1 ratio and the backcross progeny of (TGL × TR) × W fit a 1:1:1:1 ratio (Table 1, No. 9). The families within each cross were in agreement with respect to their respective types of segregation as measured by the heterogeneity χ^2. The χ^2 for joint segregation (linkage) was .24 (P = .50 – .70) in the TGL×Nan F_2 segregation and .71 (P = .30 – .50) in the TGL × TR F_2 segregation. Both values are nonsignificant.

Four F_2 families of the cross Nan × TR were grown (Table 1, No. 10). Two classes of lint color were evident; one, a dark to intermediate brown class, and the other, a light brown class resembling

TABLE 1.—*Segregation for lint color in crosses involving Texas Green Lint, Nankeen, Texas Rust, Higginbotham, and normal white lint.*

Number	Cross	Generation	Number of families	Total population	Segregation	X^2 for Deviation	P	X^2 for Heterogeneity	P
1	TGL × W	F_2	8	789	1:2:1	3.170	0.20–0.30	12.530	0.50–0.70
2	(TGL × W) × W	Backcross	3	276	1:1	1.754	0.10–0.20	2.976	0.20–0.30
3	Nan × W	F_2	5	1,333	1:2:1	4.597	0.10–0.20	7.103	0.50–0.70
4	(Nan × W) × W	Backcross	4	378	1:1	0.021	0.80–0.90	1.906	0.50–0.70
5	TR × W	F_2	6	433	1:2:1	0.670	0.50–0.90	9.890	0.30–0.50
6	(TR × W) × W	Backcross	3	132	1:1	1.480	0.20–0.30	1.71	0.30–0.50
7	TGL × Nan	F_2	2	340	9:3:3:1	3.049	0.30–0.50	7.103	0.05–0.10
8	TGL × TR	F_2	3	213	9:3:3:1	0.942	0.80–0.90	2.135	0.90–0.95
9	(TGL × TR) × W	Backcross	2	57	1:1:1:1	2.720	0.30–0.50	6.020	0.10–0.20
10	Nan × TR	F_2	4	183	3:1	0.410	0.50–0.70	22.634	<.01
11	(Nan × TR) × W	Backcross	1	41	1:1	0.025	0.80–0.90	—	—
12	(Nan × Hig) × W	Backcross	1	67	3:1	1.438	0.20–0.30	—	—
13	(TR × Hig) × W	Backcross	1	69	3:1	0.043	0.80–0.90	—	—

TR in color. Although the darker class contained individuals ranging in color from a type darker than the Nan to a type resembling intermediate Nan, it was not possible to separate them into distinct sub-classes. Therefore, they were all thrown into one class which contained approximately three-fourths of the entire population. The χ^2 for goodness of fit to a 3:1 ratio was .41 (P = .50 – .70). The heterogeneity χ^2 of 22.63 (P = less than .01) indicates that the families did not segregate in a similar manner. Small numbers in some families may have been partly responsible. A backcross progeny (Table 1, No. 11) gave 20 dark brown and 21 light brown segregates. It is significant that no white lint segregates appeared in either the F_2 or backcross populations.

Progenies of Nan × Hig F_1 backcrossed to W and TR × Hig F_1 backcrossed to W were grown for another study, but when normal white lint segregates were observed they were classified for lint color (Table 1, Nos. 12 and 13). All brown lint segregates were placed in one class. The observed segregations of both crosses did not differ significantly from a ratio of 3 brown: 1 white.

The results obtained lead to the following conclusions: (a) The lint colors, Texas Green Lint (TGL), Nankeen (Nan), and Texas Rust (TR), each are conditioned by a single gene which is incompletely dominant in crosses with white lint. (b) The gene for Texas Green Lint is independent of those for Nankeen and Texas Rust. (c) The genes for Nankeen and Texas Rust are alleles. (d) Higginbotham brown lint, though inadequately tested, appears to be conditioned by a single gene which is different from, and probably independent of, the genes for Nankeen and Texas Rust.

COLOR ANALYSIS

The 102 individual plant samples from one F_2 family of the Texas Green Lint × Texas Rust cross were studied on a color analyzer in an effort to obtain numerical values for the different color components. Once the samples from the F_2 were separated into four main classes, it was evident that each class, except white, could be separated further, thus facilitating a more critical color analysis. Since the monohybrid experiments had demonstrated incomplete dominance for both the brown lint gene and the green lint gene, and as the dihybrid experiments had shown these genes to be independent, it was expected that each of the nine possible genotypes could be recognized phenotypically. Regrouping of the main classes was attempted on this basis, the separation being made according to the appearance of the samples to the unaided eye. In no case did the numbers obtained for the various classes differ significantly from a 1:2:2:4:1:2:1:2:1 ratio, the χ^2 being .379 (P more than .90). While every effort was made to eliminate bias in breaking down the main classes into their less sharply defined sub-classes, it would appear from the high probability value obtained that some control was exercised.

Each sample was carded on a pair of old-fashioned hand cards. This operation mixed the fibers thoroughly and the resulting flattened

bat was adaptable to analysis under the Bausch and Lomb H. S. B. color analyzer. This instrument employs the principle of a visual comparison of the material to Munsell discs of known color. The method of analysis recommended by the Bausch and Lomb Optical Company (1) was followed in this study. The terminology used is that adopted by the Colorimetry Committee of the Optical Society of America (3). According to this system the components of color are, hue saturation and brilliance.

When the color of the sample and the color of the discs have been matched through the manipulation of the discs, the color of the sample may be expressed numerically. This system does not provide a method for the expression of color as one figure; instead, numbers are arranged to indicate differences according to the three color attributes. For convenience, the three figures are written as a whole number and a common fraction, the first denoting hue, the figure above the line brilliance, and the figure below the line saturation.

In this paper no attempt has been made to give the color components for each sample analyzed, but Table 2 gives the average and extreme components of color for each of the nine classes. Occasionally, a single individual fell outside the limits of probability set by the standard deviation, with respect to one of the components of color, but of the samples of lint from 102 plants examined, only one fell outside the limits of probability with respect to two components of color. In no case was there an individual out of bounds for all three color components.

The diagram[4] shown as Fig. 1 was plotted from the average color specifications given in Table 2. A definite grouping of the classes predominating in green about the green type will be noted. The white class is highest on the brilliance scale, with the intermediate brown and intermediate green lying between this class and their respective parental types. The intermediate brown and white classes have practically the same hue and both are closer to brown than to green in this respect. The intermediate green class is nearly the same as the intermediate brown in brilliance, and it lies fairly close to the parental green type in hue. The intermediate brown-intermediate green class falls between the parental types and the intermediate monohybrid types in brilliance, and while falling between the latter types in hue, it closely approaches the intermediate green in this respect. The brown-green class lies close to brown in both brilliance and hue. If the brown lint and green lint genes were equal in their expression of hue the brown-green class should have fallen on a general line between brown and green. The same is true of certain of the other classes discussed. From these data it would appear that when the brown lint gene is in the heterozygous condition, the green lint gene present either in the homozygous or heterozygous condition is the largest contributor to hue. However, when the gene for brown lint is present in the homozygous condition, the

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[4]Figure suggested by Miss Dorothy Nickerson, Color Technologist, Food Distribution Administration (formerly Agricultural Marketing Service), U. S. Dept. of Agriculture.

TABLE 2.—*Average and extreme color specifications in terms of hue, saturation, and brilliance of the nine F_2 classes of a Texas Green Lint × Texas Rust cross.*

Class	Average color specifications	Extremes of color specifications
Brown-Green	17.58YR $\frac{5.36}{3.86}$	16.57YR–17.89YR $\frac{5.11\text{–}5.85}{3.59\text{–}4.08}$
Brown—Int. Green	16.29YR $\frac{5.72}{3.94}$	15.95YR–16.66YR $\frac{5.50\text{–}5.97}{3.76\text{–}4.08}$
Int. Brown-Green	28.58Y $\frac{6.11}{3.65}$	28.20Y–28.99Y $\frac{5.94\text{–}6.23}{3.40\text{–}4.06}$
Int. Brown-Int. Green	28.47Y $\frac{6.80}{3.57}$	27.71Y–29.60Y $\frac{6.21\text{–}7.27}{2.74\text{–}4.33}$
Brown	17.53YR $\frac{5.56}{4.38}$	16.19YR–18.21YR $\frac{5.45\text{–}5.64}{4.03\text{–}5.53}$
Int. Brown	20.89Y $\frac{7.08}{3.07}$	20.41Y–21.29Y $\frac{6.55\text{–}7.26}{2.68\text{–}3.71}$
Green	30.72GY $\frac{6.16}{3.42}$	29.95Y–31.37GY $\frac{6.09\text{–}6.24}{3.18\text{–}3.57}$
Int. Green	29.56Y $\frac{7.23}{3.50}$	28.92Y–30.44GY $\frac{6.81\text{–}7.73}{3.06\text{–}4.18}$
White	21.12Y $\frac{7.92}{1.74}$	20.88Y–21.50Y $\frac{7.67\text{–}8.04}{1.62\text{–}1.84}$

green lint gene, present either in the homozygous or heterozygous condition, appears to have no measurable effect on hue.

FINENESS OF THE FIBERS

Interesting differences in the physical nature of brown and green lint are brought out by a study of the fineness of the fiber. Several season's experience in handling green lint cotton and segregates from crosses involving green lint developed the impression that the lint from homozygous green individuals was softer and silkier than either brown lint or white lint. It appeared that the fibers from pure green lint were actually finer or smaller in cross-sectional area than those from white or brown. Harland (6) and Ware (9) have reported that fine fibers seem to be completely linked with green lint.

Measurements of the fineness of the fiber, using the weight per unit length method, and the mean and upper quartile length were

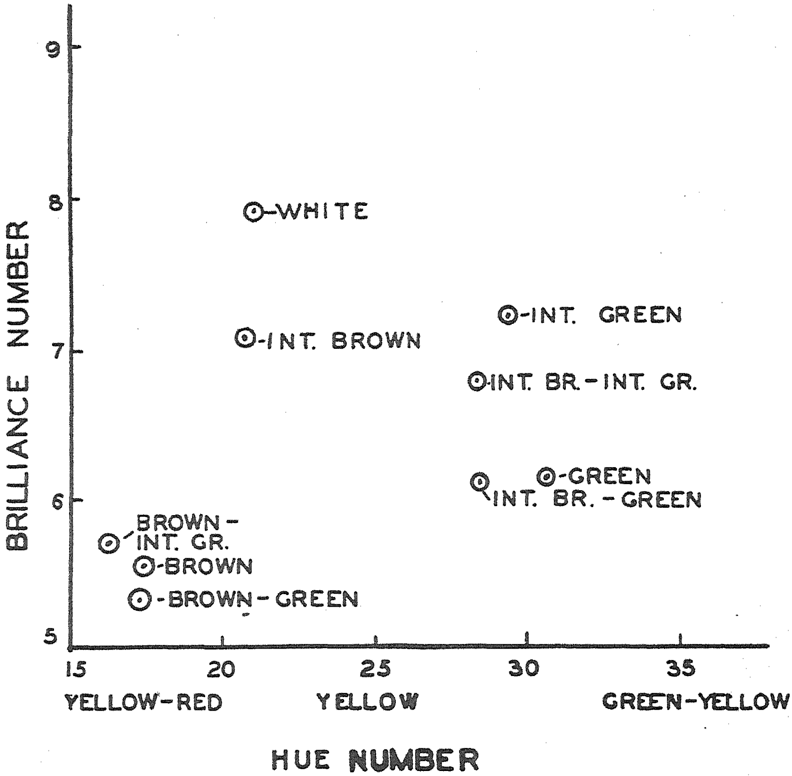

FIG. 1.—Diagram of average color specifications for each of nine F_2 classes of a Texas Green Lint × Texas Rust cross.

made on composite lint samples from each of the nine phenotypic classes of the F_2 generation of the TGL × TR cross in 1937.[5] As shown in Table 3, the homozygous classes, green, brown, white, and brown-green, weighed 3.1, 3.9, 4.6, and 2.9 micrograms per unit inch, respectively. Apparently the gene for green lint also conditions the fineness of the fiber or is completely linked with a gene with this effect, and as will be observed from its expression in various combinations, the degree of fineness is fixed within fairly well-defined limits. The brown lint gene has much the same function except that the degree of fineness falls between that of green and white. The homozygous green-brown class had the finest fibers and the homozygous white had the coarsest fibers of the nine classes on which fiber fineness determinations were made. The intermediate classes fall into place in accordance with the amount or degree of fineness con-

[5]The measurements of these fiber properties were made at the Cotton Fiber and Spinning Research Laboratory of the Food Distribution Administration (formerly Agricultural Marketing Service) in cooperation with the A. and M. College of Texas. Special acknowledgment is given to W. S. Smith in connection with these measurements.

tributed by the parents. These results suggest a case of Mendelian inheritance of a size character. Color and fineness are so closely associated as to leave little doubt that the expression of fiber fineness is an additional effect of the genes for green and brown lint, although fineness determinations on individual plants were not made, and a population sufficiently large to detect crossing over, if two closely linked genes were involved, was not grown.

TABLE 3.—*Fineness of fiber, upper quartile, and mean length of lint from composite samples from each of the nine phenotypic classes of the F_2 generation of a brown lint by green lint cross.*

Class	Mean weight/unit length inches, micrograms*	Coefficient of variability	Length at 25% point, inches	Mean length, inches	Coefficient of variability
Brown-Green	2.9	6.55	0.908	0.675	41.72
Brown—Int. Green	4.0	6.75	0.978	0.803	30.64
Int. Brown-Green	2.9	8.97	1.026	0.797	37.01
Int. Brown-Int. Green	4.2	8.57	1.084	0.887	31.12
Brown	3.9	4.87	0.983	0.778	35.73
Int. Brown	4.3	6.74	1.056	0.841	34.48
Green	3.1	6.45	0.989	0.799	33.17
Int. Green	4.0	9.50	1.050	0.874	28.83
White	4.6	9.35	1.050	0.864	29.98

*1 microgram = 10^{-3} milligrams.

SUMMARY

1. The lint colors in Texas Green Lint, Nankeen (dark brown lint), Texas Rust (light brown lint), and Higginbotham (light brown or tan lint) cotton were studied.

2. Texas Green Lint, Nankeen, and Texas Rust each are conditioned by a single gene which is incompletely dominant in crosses with white lint. The gene for Texas Green Lint is independent of those for Nankeen and Texas Rust; and the genes for Nankeen and Texas Rust are alleles. Higginbotham brown lint appears to be genetically different from, and independent of, Nankeen and Texas Rust.

3. A numerical expression of color of each segregate of a Texas Green Lint × Texas Rust cross was obtained by colorimetric analysis.

4. The respective genes for green lint and brown lint appear to inhibit the development of the fiber with respect to weight per unit length.

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TOP-ROOT RATIOS OF INBRED AND HYBRID MAIZE[1]

D. BOYD SHANK[2]

TO PRODUCE maximum yields of grain, plants must have efficient root systems for obtaining sufficient minerals and water for optimum top growth. Furthermore, their roots should be of such a nature as to prevent lodging. Since roots vary in diameter and in surface per unit weight, root surface, especially absorbing surface, would be desirable as a criterion of root value. To date no practical procedure has been devised for obtaining root surfaces rapidly, leaving weight as the most usable measure available for experiments necessitating large numbers of determinations. However, root weight alone is not a good criterion of root value as two root systems of equal weight may have to support tops of unequal size. Therefore, in the following experiments, top-root ratios, which express the relative growth of tops to roots, were used. These ratios give a balance or pattern of plant growth which has received little attention in genetic studies.

It was the object of this investigation to determine what differences exist among the top-root ratios of fixed inbred lines of maize and to determine how these differences are inherited in hybrids.

REVIEW OF LITERATURE

Schulze (8)[3] found the relationship of weight of tops to weight of roots to be 100:7.4, 100:9.0, 100:4.7, 100:9.2, 100:3.4 and 100:38.9, respectively, for mature plants of barley, oats, rye, wheat, peas, and beans.

Working with plants shortly after anthesis had set in, King (5) obtained values of 3.34:1, 2.23:1, 4.00:1 and 6.84:1 for barley, oats, clover and corn, in the order named.

Schneider (7), using 88 varieties of oats, found that among mature plants the ratio of weight of tops to weight of roots ranged from 100:28.2 to 100:10.6.

Boonstra (1), testing seven races of peas, found that the ratio of dry weight of shoot to dry weight of root varied from 8.27 to 16.76.

Weihing (12) placed a number of regional corn varieties into the three vegetative types of small, medium, and large. Top-root ratios based on dry weights of mature plants, when grown under comparable conditions, for the three types were 6.42, 4.90, and 3.47, respectively.

Harvey (3) discovered significantly different top-root ratios between inbred strains of maize.

Burkholder and McVeigh (2), working with corn inbreds and hybrids supplied with various levels of nitrogen, reported that the inbred R_4 had notably high shoot-root ratios at all nitrogen levels.

[1]Part of a thesis submitted to the graduate faculty at the Iowa State College in partial fulfillment of the requirements for the degree of doctor of philosophy. Contribution from the Genetics Section, Iowa Agricultural Experiment Station, Ames, Iowa. Journal Paper J-1128. Project 250. Received for publication June 14, 1943.

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[3]Figures in parenthesis refer to "Literature Cited", p. 987.

Holbert, *et al.* (4) found root-top ratios of 0.62, 0.66, 0.83, and 0.85 for four inbred lines of maize harvested when slightly over 8 weeks of age.

Koehler, *et al.* (6), working with two pairs of self-fertilized corn strains, found that crossing of weak- and strong-rooted plants usually resulted in an F_1 generation with little lodging. However, one cross gave F_1 plants that were practically 100% lodged. They concluded that the inheritance of tendencies for strong and weak roots cannot be explained by a single genetic factor.

Spencer (10) found that top-root ratios for two single cross corn hybrids were approximately intermediate between those of their inbred parents up to the time of silking, at which time the hybrids equaled or exceeded the inbred with the larger ratio.

MATERIALS AND METHODS

Twelve first cycle and seven second cycle yellow dent inbreds, one white flint inbred, and one yellow sweet inbred were used. (First cycle inbreds are selfs from varieties, while second cycle inbreds are recovered lines obtained by backcrossing F_1 hybrids one or two generations before inbreeding.) A brief description of the majority of the first cycle inbreds and of the reccurent parents of the second cycle inbreds may be found in Table 3, pages 504 to 519 of the 1936 Yearbook of the U. S. Dept. of Agriculture.

All but one of the strains were secured through the courtesy of E. W. Lindstrom. The single exception, LE23, was obtained from the Pioneer Hi-Bred Corn Company of Johnston, Iowa.

Plants for root studies were grown in the greenhouse for periods of from 4 to 6 weeks in the three mediums, aqueous solution, soil, and sand. The general method of handling each will be given separately.

For water cultures two different solutions were employed. These were modifications of the one used by Smith (9) and of the buffered solution Zinzadzé (13) recommended for constant pH. Basically they were made up as follows:

Modified Smith's solution		Buffered solution	
Salt	Grams per liter of solution	Salt	Grams per liter of solution
KCl	0.288	KCl	0.286
$MgSO_4.7H_2O$	0.432	$MgSO_4.7H_2O$	0.500
$Ca(NO_3)_2.4H_2O$	0.469*	NH_4NO_3	0.286
$(NH_4)_2SO_4$	0.115	$Ca_3(PO_4)_2$	0.500
KH_2PO_4	0.066		

*This solution contains 80 p.p.m. of nitrogen. In some of the earlier experiments a concentration of only 40 p.p.m. was used. These experiments will be designated.

Colloidal $Ca_3(PO_4)_2$ for the buffered solution was prepared by dissolving 13.69 grams of K_3PO_4 in 1 liter of warm water while 10.73 grams of anhydrous $CaCl_2$ were dissolved in a second liter of warm water. The two solutions were then mixed with vigorous stirring, giving a finely divided suspension of $Ca_3(PO_4)_2$ containing KCl in solution. This solution was used as made up at the rate of 100 ml per liter of nutrient solution.

Iron, in the form of ferric tartrate, was added as needed by the plants. The supply of micro-nutrients was furnished by impurities in the C.P. salts and in the tap water used for all cultures.

Solutions were changed every 5 to 14 days, depending on the time of year and

size of the plants. Tap water was added between solution changes as needed to replace that lost by transpiration and evaporation.

Methods of obtaining seedling plants and setting them up in water cultures were similar to those described by Harvey (3). In all tests, plants were grown in painted quart Mason jars which had been treated with formalin before using to reduce fungal growth. Two seedlings per jar constituted a unit.

For soil cultures, mixtures of 3 parts of compost to 1 part top soil and 1 part sand put through an 8-mesh seive and thoroughly mixed, were used. However, this ratio was often varied as the lots of compost and top soil differed widely in fertility.

The purpose of the sand cultures was to provide a medium for plant growth of slightly different structure than soil cultures and one that was low in plant food. Washed river sand was used as the growing medium. A reduced concentration of the modified Smith's solution was added every 3 or 4 days in order to maintain limited plant growth.

Seed of each line used was a composite of two or three ears. Before using, the kernels were treated with either "Merko" or "New Improved Semesan Jr." mercury dusts.

All experiments conducted were set up in a completely randomized block design and analyses of variance were calculated on the data according to the method outlined by Snedecor (11). Rerandomization within replications was effected at weekly intervals.

In harvesting, roots of sand and soil culture plants were first carefully washed over a screen, then soaked for 3 or 4 hours and rewashed.

Dry weights in grams were obtained on tops and roots after they had been oven dried to a constant moisture level. The top-root ratios reported are the quotients obtained by dividing the dry weight of the tops by the dry weight of the roots.

EXPERIMENTAL RESULTS

DIFFERENCES IN TOP-ROOT RATIOS OF INBRED LINES

Test 1 consisted of 10 inbreds grown from May 3 to May 31, 1939, on the three cultures outlined above. Inbreds used ranged from strong to weak rooted ones as observed under field conditions. Water culture plants were raised on the buffered solution. Eight replications were used, giving 240 units. A summary of the mean top-root ratios is presented in Table 1 and the analysis of variance in Table 2.

Of primary interest in these studies was the fact that wide differences existed between the mean top-root ratios of the different lines. Based on all three cultures, means ranged from 1.40 to 2.07, the values for the various lines being spread rather uniformly over this range. In the analysis of variance (Table 2), line variation is highly significant, showing that these differences between strains were real under the conditions of this test. Ratios exhibited by individual lines agreed rather closely with their lodging resistance as observed in the field. KR(Osf), Hy, and KR, lines which are resistant to lodging, exhibited low ratios, i.e., a large amount of roots in proportion to tops, while PR and R_4, which usually lodge, had high ratios. In general, the lines were consistent in that they occupied about the same relative rank on all three cultures.

TABLE 1.—*Mean top-root ratios of ten inbreds as calculated from dry weights, test 1.*

Inbred	Culture			Mean
	Water	Soil	Sand	
KR (Osf)	2.03	1.27	0.90	1.40
Hy	1.79	1.73	1.05	1.52
KR	2.19	1.76	1.03	1.66
TR (Ldg)	2.27	1.85	1.00	1.71
Osf	2.19	2.11	1.08	1.79
Ldg (PR)	2.54	1.93	1.02	1.83
WCR	2.19	2.18	1.34	1.90
M14	2.12	2.22	1.40	1.91
R_4	2.63	2.21	1.33	2.06
PR	2.62	2.24	1.34	2.07
Mean	2.26	1.95	1.15	1.79

TABLE 2.—*Analysis of variance based on top-root ratios, test 1.*

Source of variation	Degrees of freedom	Mean square
Replications	7	0.07
Lines	9	1.13**
Cultures	2	26.08**
Lines × cultures	18	0.24**
Error	203	0.05
Total	239	

**P less than 0.01.

The cultures account for the bulk of the variance in the analysis. The smallest mean difference between any two cultures was 0.31, existing between water and soil cultures. The standard error for a culture mean difference was ±0.04, making this highly significant.

That all lines did not respond the same to the three cultures is shown by the significance of the interaction of lines × cultures.

Test 2 was conducted to determine if the general results of test 1 could be repeated, especially under the changed environmental conditions existing during a different season of the year and with a longer period of plant growth. Nine inbreds were grown from June 28 to August 11, 1939. LE23, Osf(KR), and Idt(Baw) replaced M14, WCR, Osf, and Ldg (PR) of test 1. Modified Smith's solution with a nitrogen concentration of 40 p.p.m. was used in place of the buffered solution for water cultures. Tables 3 and 4 present the mean top-root ratios and the analysis of variance, respectively.

As in test 1, lines, cultures, and the interaction of lines × cultures were highly significant. In general, ratios in test 2 were slightly higher than in test 1. The explanation for this difference may have been that the plants in the second experiment were older, since top-root ratios increase with age (1, 10).

The six lines common to both test 1 and test 2 occupied the order

TABLE 3.—*Mean top-root ratios of nine inbreds as calculated from dry weights, test 2.*

Inbred	Culture			Mean
	Water	Soil	Sand	
Osf(KR)	2.46	1.87	1.61	1.98
KR(Osf)	2.12	2.55	1.61	2.09
KR	2.55	2.38	2.09	2.34
Hy	2.55	2.23	2.31	2.36
Idt(Baw)	2.78	2.05	2.31	2.38
LE23	3.15	2.53	1.97	2.55
TR(Ldg)	2.80	2.73	2.34	2.63
R_4	3.07	2.64	2.19	2.64
PR	3.16	3.88	2.33	3.12
Mean	2.74	2.54	2.09	2.45

TABLE 4.—*Analysis of variance based on top-root ratios, test 2.*

Source of variation	Degrees of freedom	Mean square
Replications	5	0.45
Lines	8	2.03**
Cultures	2	6.05**
Lines × cultures	16	0.62**
Error	130	0.17
Total	161	

**P less than 0.01.

of KR(Osf), Hy, KR, TR(Ldg), R_4, and PR in test 1 when arrayed from low to high ratios. In test 2 they were in the same sequence, except for KR and Hy, which were reversed. This tends to substantiate the ranking in test 1.

Top-root ratios of additional inbred lines were determined in test 3. The test was conducted in the same manner as test 2, except nitrogen was raised to 80 p.p.m. in the water cultures.

Ten inbreds were used which included eight new strains and two, KR and PR, which were included in tests 1 and 2. Since KR has a low and PR a high top-root ratio, they were included as checks for a comparative evaluation of the ranking of the strains between tests. The plants were grown from March 2 to April 15, 1940.

Mean top-root ratios appear in Table 5 and the analysis of variance in Table 6. As in tests 1 and 2, lines, cultures, and the interaction of lines × cultures were all highly significant. Two lines had lower means than KR and two higher than PR.

Throughout these tests individual inbred lines exhibited characteristic differences in the coarseness or diameter of primary and corresponding lateral roots. This was particularly true of water culture plants. Since the finer the roots, the greater surface a given weight will have, the root systems of test 3 were graded at harvest time on the basis of their relative coarseness into five numerical

TABLE 5.—*Mean top-root ratios of 10 inbreds as calculated from dry weights, test 3.*

Inbred	Culture			Mean
	Water	Soil	Sand	
ITE	2.06	1.24	1.11	1.47
Ldg	2.03	1.47	1.42	1.64
KR	1.99	1.72	1.24	1.65
Ldg(K)	2.28	2.07	1.41	1.92
Bls	2.86	1.79	1.28	1.98
Mc	2.85	1.98	1.45	2.09
La(Bls)	2.69	2.04	1.61	2.11
PR	3.06	2.11	1.63	2.27
WF	3.78	1.77	1.55	2.36
GB134	4.17	2.50	2.10	2.92
Mean	2.78	1.87	1.48	2.04

TABLE 6.—*Analysis of variance based on top-root ratios, test 3.*

Source of variation	Degrees of freedom	Mean square
Replications	7	0.02
Lines	9	4.27**
Cultures	2	35.40**
Lines × cultures	[illegible]	[illegible]
Error	[illegible]	[illegible]
Total	239	

**P less than 0.01.

classes. Such wide differences in general root structure existed among the treatments, water culture producing coarse roots, soil culture intermediate to fine, and sand culture fine roots, that each culture was graded independently of the others. The mean grade for each line grown on each culture is presented in Table 7.

TABLE 7.—*Mean root grades of 10 inbreds, test 3.**

Inbred	Culture		
	Water	Soil	Sand
ITE	1.8	3.3	2.6
Ldg	5.0	4.8	5.0
KR	4.9	3.0	3.5
Ldg(K)	4.8	2.9	3.6
Bls	3.3	1.3	2.6
Mc	3.1	3.8	3.9
La(Bls)	4.4	2.9	2.9
PR	2.3	1.6	1.6
WF	1.3	1.5	1.5
GB134	1.0	2.3	1.0

*Grades are 1, fine primaries and fine laterals; 2, medium primaries and fine laterals; 3, medium primaries and medium laterals; 4, coarse primaries and medium laterals; and 5, coarse primaries and coarse laterals.

Individual lines were not consistent in their relative ranking between cultures. This may have been due to actual differences as caused by culture or to inaccuracies of classification. Under the conditions of this experiment, GB134, WF, and PR were relatively fine rooted, while Ldg, KR, and Ldg (K) were consistently coarse rooted.

INHERITANCE OF TOP-ROOT RATIOS IN F_1 HYBRIDS

Two tests were conducted using inbreds which had exhibited wide ratio differences (in tests 1, 2, or 3) and single crosses between them. The experiments were handled in the same manner as were those for the inbreds.

Test 4 contained two pairs of inbreds, each pair consisting of two lines with widely differing top-root ratios, and reciprocal hybrids between lines within each pair. Eight replications were grown from June 20 to August 2, 1939. Smith's solution, containing 40 p.p.m. of nitrogen, was used for the water cultures. Mean top-root ratios are given in Table 8 and their analysis of variance in Table 9.

TABLE 8.—*Mean top-root ratios of inbreds and hybrids as calculated from dry weights, test 4.*

Line	Culture			Mean
	Water	Soil	Sand	
[illegible]	3.18	3.61	2.72	3.17
[illegible]R × Hy	2.21	2.09	1.83	2.05
Hy × PR	2.17	2.24	1.71	2.04
Hy	2.30	2.63	2.03	2.32
R_4	2.78	2.58	2.28	2.55
R_4 × KR	2.68	2.25	1.98	2.30
KR × R_4	2.79	2.11	1.86	2.25
KR	2.55	2.44	1.77	2.25
Mean	2.58	2.49	2.02	2.37

TABLE 9.—*Analysis of variance based on top-root ratios, test 4.*

Source of variation	Degrees of freedom	Mean square
Replications	7	0.46
Lines	7	3.14**
Cultures	2	5.81**
Lines × cultures	14	0.32**
Error	160*	0.11
Total	190	

*One degree of freedom subtracted for a datum supplied by missing plot technic.
**P less than 0.01.

Mean ratios for the F_1 hybrids were either the same or very nearly the same as those of their lower ratio parent. Reciprocal hybrids did not differ in their mean top-root ratios.

Mean ratio differences between F_1 hybrids and their high ratio parents and between hybrids and their low ratio parents appear in Table 10. The total mean difference between the high ratio parents and the hybrids, based on all three cultures, was highly significant ($+2.79 \pm 0.24$), while that between the low ratio parents and the hybrids was significant only at the 5% level ($+0.61 \pm 0.24$). Since hybrid ratios were always subtracted from those of their parents to obtain the differences in Table 10, the positive values indicate that in this test hybrid ratios were actually slightly lower than were those of their low ratio parents.

TABLE 10.—*Mean differences in top-root ratios between hybrids and their high ratio parents and between hybrids and their low ratio parents, test 4.*

Hybrid	Culture			Mean
	Water	Soil	Sand	
High Ratio Parent Minus Hybrid				
PR × Hy	+0.97	+1.52	+0.89	+1.13
Hy × PR	+1.01	+1.37	+1.01	+1.13
R_4 × KR	+0.10	+0.33	+0.30	+0.24
KR × R_4	−0.01	+0.47	+0.42	+0.29
Sum	+2.07	+3.69	+2.62	+2.79
S. E. of sum	±0.41	±0.41	±0.41	±0.24
Low Ratio Parent Minus Hybrid				
PR × Hy	+0.09	+0.54	+0.20	+0.28
Hy × PR	+0.13	+0.39	+0.32	+0.28
R_4 × KR	−0.13	+0.19	−0.21	−0.05
KR × R_4	−0.24	+0.33	−0.09	+0.00
Sum	−0.15	+1.45	+0.22	+0.61
S. E. of sum	±0.41	±0.41	±0.41	±0.24

Mean differences between the hybrids and their high ratio parents were highly significant for each culture. When hybrid ratios were compared with those of their low ratio parents for each culture, only the value for soil ($+1.45 \pm 0.41$) attained significance. By comparing this value with those for water cultures and sand, i.e., $+1.45 - (-0.15 + 0.22)/2$, a value of $+1.41 \pm 0.51$ is obtained. The corresponding comparison involving the differences between the means of the hybrids and their high ratio parents gives a value of $+1.35 \pm 0.51$. These two comparisons are both highly significant, indicating that significance of the interaction of lines × cultures in the analysis of variance was partially caused by the failure of inbreds and hybrids to behave relatively the same when grown on soil as when grown on sand and water cultures. The cause of such a differential reaction is not known. Other interaction components tested proved to be nonsignificant.

Test 5, containing five inbreds and five F_1 hybrids, was grown from April 2 to May 11, 1940. Nitrogen in the water cultures was

maintained at 100 p.p.m. Mean top-root ratios are given in Table 11 and the statistical analysis in Table 12.

TABLE 11.—*Mean top-root ratios of inbreds and hybrids as calculated from dry weights, test 5.*

Line	Culture			Mean
	Water	Soil	Sand	
KR(Osf)	1.54	1.33	0.88	1.25
KR(Osf) × Hy	1.39	1.30	0.95	1.21
Hy	1.66	1.57	1.06	1.43
Hy × KR	1.51	1.28	0.94	1.24
KR	1.50	1.39	0.99	1.29
KR × PR	1.85	1.36	0.98	1.40
PR	2.93	2.04	1.41	2.13
PR × R_4	2.17	1.63	1.15	1.65
R_4	2.42	2.01	1.47	1.97
PR × KR(Osf)	1.60	1.25	0.95	1.27
Mean	1.85	1.52	1.08	1.48

TABLE 12.—*Analysis of variance based on top-root ratios, test 5.*

Source of variation	Degrees of freedom	Mean square
Replications	7	0.08
Lines	9	2.55**
Cultures	2	12.07**
Lines × cultures	18	0.24**
Error	203	0.02
Total	239	

**P less than 0.01.

The results are similar to those of test 4. Mean top-root ratios for individual hybrids were again very similar in size to those of their low ratio parents. This held true whether individual hybrids were composed of two relatively high, two low, or a high and a low ratio inbred. That hybrid ratios as a group were slightly lower than those of their low ratio parents is evident in Table 13. The mean difference based on all three cultures was $+0.29 \pm 0.11$ which is significant at the 5% level. As in test 4, soil was the only individual culture on which hybrids had a significantly lower mean ratio than that of their low ratio inbreds.

The fact that a greater difference existed between F_1 hybrids and their low or high ratio inbreds when grown on soil as compared with the other two cultures, accounts for part of the significant interaction of lines × cultures $(0.63-(-0.02+0.24)/2 = 0.52 \pm 0.23$ for hybrids compared with their low ratio parents, 0.69 ± 0.23 for hybrids compared with their high ratio parents). Several other significant comparisons were found, but no consistent results pointing to inherited differences between inbred and hybrid ratios were discovered.

TABLE 13.—*Mean differences in top-root ratios between hybrids and their high ratio parents and between hybrids and their low ratio parents, test 5.*

Hybrid	Culture			Mean
	Water	Soil	Sand	
High Ratio Parent Minus Hybrid				
KR(Osf) × Hy	+0.27	+0.27	+0.11	+0.22
Hy × KR	+0.15	+0.29	+0.12	+0.19
KR × PR	+1.08	+0.68	+0.43	+0.73
PR × R_4	+0.76	+0.41	+0.26	+0.48
PR × KR(Osf)	+0.82	+0.76	+0.52	+0.70
Sum	+3.08	+2.41	+1.44	+2.28
S. E. of sum	±0.19	±0.19	±0.19	±0.11
Low Ratio Parent Minus Hybrid				
KR(Osf) × Hy	+0.15	+0.03	−0.07	+0.04
Hy × KR	−0.01	+0.11	+0.05	+0.05
KR × PR	−0.35	+0.03	+0.01	−0.10
PR × R_4	+0.25	+0.38	+0.32	+0.32
PR × KR(Osf)	−0.06	+0.08	−0.07	−0.02
Sum	−0.02	+0.63	+0.24	+0.29
S. E. of sum	±0.19	±0.19	±0.19	±0.11

Grades based on the relative coarseness of the root systems were taken in the same manner as were those in test 3. Results are given in Table 14. Hybrids were either intermediate or as coarse as the parent with the coarser type of roots.

TABLE 14.—*Mean root grades based on texture, test 5.*

Line	Culture		
	Water	Soil	Sand
KR(Osf)	4.0	2.9	4.1
KR(Osf) × Hy	4.4	4.0	4.1
Hy	3.5	2.9	3.8
Hy × KR	3.3	4.8	4.0
KR	3.5	3.9	4.9
KR × PR	3.1	3.3	2.9
PR	2.3	2.5	1.5
PR × R_4	3.6	3.6	2.6
R_4	2.8	1.6	1.9
PR × KR(Osf)	3.9	3.8	3.5

DISCUSSION

In order for plants to have survived under the force of natural selection there must be some mechanism controlling the balance between top and root growth. In the present investigation, by the use of homozygous inbred lines of corn and controlled environmental

conditions, it has been demonstrated that rather large inherited differences in top-root ratios may exist within a species. Although top-root ratios were altered for all strains by different environments (soil, low nutrient sand, and nutrient water cultures as growing mediums), inbreds occupied approximately the same rank from one environment to another. Inbreeding has thus isolated genes which tend to control the proportion of tops to roots. That several genes are involved is evident from the fact that when numerous inbreds were grown under similar environmental conditions they displayed a continuous range of ratios rather than a few distinct classes.

Top-root ratios for F_1 hybrids of inbred lines possessing different ratios either did not differ or were only slightly different from those of their lower ratio parents in all cases. This was true whether the hybrid combination consisted of a high and a low, two high, or two low ratio inbreds. Such results would indicate a dominance of factors for low top-root ratios.

Thus, a hybrid, despite the fact that it may show hybrid vigor and produce more total top growth than either parent, will still produce enough roots so that the proportion of roots to tops is similar to that of the parent possessing relatively more roots. This is of distinct advantage both from the standpoint of lodging resistance and nutrient absorption. Since the proportion of tops to roots is the same for hybrids as for their low ratio parents, the necessity of selection for strong-rooted inbreds is apparent if it is desired to obtain hybrids with relatively large root systems.

Smith (9) found dominance in inheritance of the branched root type. Since it has been shown in this study that hybrids have as much root weight per unit of top weight as have their stronger rooted parents, it may be assumed that the absorbing surface of hybrid roots per unit of top weight is at least as great as that of their inbred with the largest surface.

Interactions of lines $\times$ cultures were significant for all tests. It is entirely possible that in individual lines there are genetic factors which cause the top-root ratio response to culture to be different than the group response. No attempt was made to study this point.

SUMMARY

Testing 21 different inbred strains of maize, heritable differences in top-root ratios, based on dry weights, were exhibited in each of three tests. Plants were grown for 4 to 6 weeks in the greenhouse on the three culture mediums soil, low nutrient sand, and nutrient aqueous solution.

The range of inbred ratio means in each test was large with individual line means being distributed uniformly throughout these ranges. This was interpreted to indicate that several genetic factors control top-root ratios.

Lines common to two or more tests occupied, in general, the same relative rank in ratio size in each test. Inbreds displayed approximately the same rank from one culture to another.

F_1 hybrids produced top-root ratios approximately equal in size to those of their low ratio parents. This was interpreted to indicate

dominance of genetic factors for low top-root ratios. Reciprocal hybrids, included in one test, did not differ significantly in top-root ratios.

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EFFECT OF BORON DEFICIENCY ON THE SOLUBLE NITROGEN AND CARBOHYDRATE CONTENT OF ALFALFA[1]

P. N. SCRIPTURE AND J. S. MCHARGUE[2]

LITTLE is known as to the function of boron in plant growth and metabolism. The purpose of the investigation described in this paper was to determine whether boron is a factor in the absorption of nitrogen and the synthesis of carbohydrates. The present investigation is limited to the water-soluble nitrogen and carbohydrate fractions of the alfalfa plant tissues.

CULTURAL METHODS

The alfalfa plants were grown in the greenhouse in sand cultures. Ten 2-gallon, glazed earthenware jars were filled with purified quartz sand which had been washed with hydrochloric acid and distilled water. Each jar had a hole in the bottom to allow continuous drainage. The hole was covered with a watch glass before adding the sand. Twenty seeds of the Grimm variety of alfalfa were planted in the sand and after germination each culture was thinned to 10 plants of uniform size and vigor. Nutrient solution was supplied by the continuous-drip procedure described by Shive and Robbins (7).[3] The flow was so regulated as to keep the sand always moist. The cultures were washed at weekly intervals by flushing with distilled water. This is necessary to prevent accumulation of unused salts. The nutrient solution used consisted of the following: KH_2PO_4, 0.0015 molar; $MgSO_4.7H_2O$, 0.0022 molar; and $Ca(NO_3)_2.4H_2O$, 0.0019 molar.

Zinc and manganese were supplied at the rate of 1 p.p.m. each. Zinc sulfate ($ZnSO_4.7H_2O$) and manganous sulfate ($MnSO_4.4H_2O$) were used as sources of these elements. Sufficient iron was supplied as ferrous ammonium sulfate to prevent chlorosis from lack of iron. All chemicals were of reagent grade and were spectroscopically boron-free. Boron was supplied as boric acid to all cultures at the start of the experiment and at the rate of 0.5 p.p.m. of solution.

When the alfalfa plants were about 5 inches high, boron applications were discontinued on five of the cultures, but the other nutrients were left unchanged.

The first visible symptoms of boron deficiency were observed about 20 days after the application of this element was discontinued. The youngest leaves of the plants presented a slightly roughened and thickened appearance. Within a week, growth of the terminal buds had virtually ceased and the affected leaves presented the characteristic yellow and yellow-bronze colorations. At the time of sampling, 3 weeks later, the plants which had received boron continuously were nearly twice the size of the boron-deficient plants.

METHODS OF CHEMICAL ANALYSIS

Sampling.—Sampling was done during days of clear weather. It being impossible to take all the samples on one day, care was taken so that all sampling was

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[2]Assistant Chemist and Head of Department, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 992.

done at the same hour each day. Since it was desired to study the composition of the soluble materials in the plant, a method for securing plant extracts described by Chibnall (2) was used. The plants were cut off at the surface of the sand and the green weight obtained at once. The material was then immersed in dry ethyl ether for 1 minute, removed, and the excess ether allowed to drain away. The material, wrapped in several thicknesses of cheesecloth, was then subjected to pressure of 6,000 pounds per square inch for 5 minutes in a Carver press. The residue was removed from the press, moistened with 0.002 N HCl, and after standing for 15 minutes, pressed again at the same pressure and for the same length of time. This treatment was repeated three times. All extracts were combined and boiled for about 1 minute to precipitate any heat-coagulable proteins, filtered into a 250-cc volumetric flask, and after cooling to room temperature, made to volume with distilled water. The extracts were kept in the refrigerator until the analytical work was completed.

According to Chibnall, the treatment with ether effects a plasmolytic action on the protoplasm of the plant cells so that it is possible to press out the water-soluble vacuolar material. The extract obtained in this experiment was a clear yellowish-brown colored solution which contained no chlorophyll.

Total nitrogen, ammonia nitrogen, amide nitrogen, nitrate nitrogen, direct reducing sugars, and reducing sugars after hydrolysis with invertase were determined in the extract.

Total nitrogen.—Since the extracts contained nitrate nitrogen, it was necessary to use a modified Kjeldahl method. The iron reduction method of Pucher, Leavenworth, and Vickery (6), carried out on a micro-scale using 5 cc of the extract, was used. A micro-distillation apparatus described by Kirk (4) was used for the distillation. The distillate was collected in an excess of standard 0.02 N H_2SO_4 and the excess acid back-titrated in the usual manner.

Ammonia nitrogen.—Ammonia was determined on 10 cc of the extract in the aeration tube of the Van Slyke-Cullen urea apparatus made alkaline with 52% potassium carbonate and aerated for 1 hour. The ammonia liberated was distilled into 0.02 N H_2SO_4 and the excess acid back-titrated. Several drops of tributyl citrate effectively prevents foaming during aeration.

Amide nitrogen.—Nitrogen present as asparagine or other similar amide compound was determined by mild acid hydrolysis. A 10-cc aliquot of the extract was boiled in the Van Slyke-Cullen aeration tube with 0.6 cc of concentrated H_2SO_4 for 2½ hours, under a reflux condenser to maintain the volume of solution constant. Addition of several porcelain chips prevents serious bumping. After the hydrolysis, the tube and its contents were cooled to room temperature and neutralized with 40% sodium hydroxide, using methyl red as an indicator. From this point the determination was carried to completion in the same manner as for the ammonia determination described above. The value found for ammonia nitrogen serves as a blank for the amide nitrogen determination.

Nitrate nitrogen.—Nitrate nitrogen was determined according to the Jones (1), modification of the Robertson method, using 5 cc of the extract. The method was conducted on a micro scale as described above for total nitrogen.

Direct reducing sugars.—The Phillips (5) modification of the Bertrand titration procedure was used. Ten cc of the extract in a 100-cc volumetric flask was made to about 50 cc with water, and 1 cc of saturated neutral lead acetate was added and thoroughly mixed. After standing 15 minutes, the solution was made to volume and filtered into a small Erlenmeyer flask containing sufficient dry sodium oxalate to remove excess lead completely. The flasks were covered and

placed in the refrigerator overnight to complete the precipitation of the lead. After filtering, 10-cc aliquots were taken for analysis. The procedure was standardized, using pure glucose.

Reducing sugars after invertase hydrolysis.—To 10 cc of the clarified extract, 5 drops of 10% acetic acid and 4 drops of invertase solution were added. The tubes were covered and allowed to stand overnight at room temperature (about 25° C). The amount of invertase required was determined by preliminary standardization of the method with C. P. sucrose. The results are calculated as reducing sugars found after hydrolysis.

RESULTS OF ANALYSES

The results of analyses for the several soluble nitrogen fractions are presented in Table 1. Values are all given as percentages of fresh plant weight.

TABLE 1.—*Percentages of the soluble nitrogen fractions in fresh alfalfa plants.*

Extract No.	Total soluble N, %	Ammonia N, %	Amide N, %	Nitrate N, %	N in other soluble forms, %
			Normal Plants		
1	0.1416	0.0013	0.0066	0.0259	0.1078
2	0.1024	0.0022	0.0075	0.0128	0.0799
3	0.1343	0.0020	0.0053	0.0144	0.1126
4	0.1380	0.0013	0.0061	0.0121	0.1185
Mean...	0.1291	0.0017	0.0064	0.0163	0.1047
			Boron-deficient Plants		
1	0.1963	0.0028	0.0320	0.0038	0.1577
2	0.1562	0.0026	0.0173	0.0000	0.1363
3	0.2293	0.0022	0.0233	0.0074	0.1964
4	0.1905	0.0021	0.0180	0.0002	0.1702
Mean...	0.1931	0.0024	0.0227	0.0028	0.1652

The results of analyses of the extracts for direct reducing sugars and reducing sugars obtained after hydrolysis with invertase are given in Table 2. All values are given as percentages of the fresh plant weight.

The results presented in Tables 1 and 2 were examined statistically and the mean differences in various constituents determined in the normal and boron-deficient plants were found to be significant.

DISCUSSION

The abnormal accumulation of total soluble nitrogen and sugars in the boron-deficient plants suggests that protein metabolism may not be proceeding normally, as proteins are usually formed when amides, such as asparagine, and sugars are both present in excess. It may be that boron plays some part in this reaction since it is known to have considerable affinity for compounds having OH groups, such as alcohols and carbohydrates.

TABLE 2.—*Percentages of direct reducing sugars and additional reducing sugars after hydrolysis in fresh alfalfa plants.*

Extract No.	Direct reducing sugars, %	Additional sugars after hydrolysis, %
Normal Plants		
1	0.3820	0.2576
2	0.4306	0.4598
3	0.5115	0.3210
4	0.3645	0.3705
Mean	0.4222	0.3522
Boron-deficient Plants		
1	0.6930	0.5111
2	0.6869	0.2995
3	1.0260	0.6475
4	0.7198	0.5676
Mean	0.7814	0.5064

On the other hand, storage proteins may be disintegrating in the affected leaves and terminal buds that die. This could account for the accumulation of soluble nitrogen but not necessarily for the excess sugars; for though the carbon chains for the protein molecules may be derived from sugars, it is not probable that the sugars are regenerated when the proteins are split by enzymatic activity.

Johnston and Dore (3) in their work with boron-deficient tomato plants found that sugars accumulated in the leaves but not in the stems. They concluded that the sugars accumulated because the conducting tissues of the leaves and stems were injured by the lack of boron and were no longer able to function in transporting materials from the leaves to other parts of the plant. Studies by Warington (8) on the broad bean and other plants indicate that a lack of boron does cause injury to the phloem cells. Johnston and Dore did not investigate the nitrogen relationship in the tomato plant so no comparison is available on this point.

A considerable difference in the content of nitrate nitrogen was also found. The boron-deficient plants were apparently able quickly to reduce absorbed nitrates to ammonia and thence to amide or other soluble nitrogen compounds. Whether boron is involved in these transformations is impossible to state with the information at hand.

Further work on these nitrogen-carbohydrate relationships will be necessary in order to verify these hypotheses.

SUMMARY

1. Alfalfa was grown in purified sand culture in the greenhouse under conditions where boron was deficient. Extracts of the plant tissue were obtained by means of a press and analyzed for nitrogeneous constituents and reducing sugars.

2. Soluble nitrogen compounds, including amides, ammonia, and nitrogen in other forms, were found to be present in larger proportions in the boron-defficient plants than in those growing normally.

3. Sugars were found to be present in excess in the boron-deficient plants.

4. The possibility that boron may be involved in protein metabolism is suggested.

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BOOK REVIEWS

PLANTS AND VITAMINS

By W. H. Schopper; translated by Norbert L. Noecker. Waltham, Mass.: Chronica Botanica; New York: G. E. Stechert and Co. XIV+293 pages, illus., 1943. $4.75.

THIS excellent book dealing with the importance of vitamins as related to plants is now presented in an English edition. Nearly ten years have passed since Professor Schopfer presented evidence that a specific chemical factor, thiamin, was necessary for the growth of certain plant life. As a result of his findings, interest in the significance of vitamins to plant growth was widened and this book is a collection of the author's studies and a review of the researches which have resulted from them. No effort has been made to mention all publications dealing with plants and vitamins, but only those which are relevant to the subject discussed by the author are included.

The book opens with a discussion on research technic when studying growth factors, and reviews the problems encountered in the preparation of good synthetic media for growing the test plants. The difference between various organic substances which may stimulate growth and the true vitamin action are considered and the stimulator agents classified. The chemical and physiological properties of the present known vitamins are next reviewed before their action on the embryo, roots, tissue cuttings, and formation of plant organs is discussed. Considerable space is devoted to a consideration of thiamin and its components—a field in which the author is an authority.

Particularly noteworthy are two chapters on the synthesis of vitamins in plants, for while there is relatively little known about this phenomenon, the author has collected available information and presented general ideas. The history of the bios factors is dealt with in an interesting manner and the evidence for the chemical identity of these substances is presented in terms of our present knowledge of the vitamins of the B complex. The requirements of different types of bacteria, such as the lactic acid, nitrogen-fixing, and hemophilic organisms, are reviewed in terms of growth factors. An effort has been made to correlate the action of vitamins as coenzymes and also their relationship to plant and animal hormones.

The section dealing with the role of vitamins in agriculture, especially as nutrients found in the soil, merits inspection. Attention is also paid to the relationship of vitamins to sexuality, symbiosis, and parasitism. The concluding chapter concerns the utility of microorganisms in vitamin analysis where there is a rather unprejudiced discussion of the biological assay of thiamin.

The book should be of value to all interested in vitamins and plant growth and, in particular, to botanists and plant physiologists. Though the author might have been more direct in mode of discussion at times, in general, the arrangement of the material presented is good and the overlapping of subject matter is not serious when one considers the ramifications of vitamin functions throughout plant metabolism. (J. C. M.)

ARTIFICIAL MANURES

By Arthur B. Beaumont. New York: Orange Judd Pub. Co., Inc. 155 pages, illus. 1943. $1.50.

THIS small volume by the former agronomist at Massachusetts State College is a simple and popular presentation of the importance of soil organic matter, manures of various kinds, and especially the making of composts and artificial manures for farm and garden use. The author first lays a simple background through a discussion of soils, soil formation and management, and the functions of organic matter and humus in agriculture. The Richards and Hutchinson method is then discussed with practical details of its use in both large- and small-scale operations. Some attention is also paid to green manuring and sheet composting.

The volume carries an index, an appendix with the composition of all kinds of materials usable in making manures, and a list of 26 selected references. It should prove useful and practical. (R. C. C.)

"STUDENT'S" COLLECTED PAPERS

Edited by E. S. Pearson and John Wishart, with a foreword by Launce McMullen. Issued by the Biometrika Office, University College, London, and printed by the University Press, Cambridge, XIV+224 pages, illus. 1942. 15/.

IN READING this book the reviewer was impressed by four features, (1) the honoring of William Sealy Gosset ("Student") by his colleagues through bringing his printed contributions together

in one volume; (2) the excellent biography by McMullen; (3) the fine spirit of cooperation shown by the editors of various technical journals in granting permission for republishing the articles in the present volume and especially the Trustees of *Biometrika* for accepting the responsibility for publication; and (4) the value to statisticians everywhere of having these contributions in a single volume.

The publishing of Student's collected papers as a monument to this pioneer worker in small sample statistics will cause him to be more widely appreciated than could have been accomplished by the placing of a bronze tablet or by the erection of a stone monument. The editors are to be commended for the planning and execution of this idea. As one reads the biographical sketch of Mr. Gosset in the foreword he is impressed how much the book would have lacked had this and the photograph been omitted. Furthermore, one sees that Mr. Gosset was intensely practical and used statistics as a tool to evaluate his experiments rather than to use the experiments to display his prowess as a mathematician, a far different attitude than is evident in the writings of some biologists. His writings consist of 21 papers and a number of miscellaneous contributions.

Within the past 20 years numerous books dealing chiefly with small sample statistics have appeared in which the investigations of "Student" are discussed and references given to his published papers. Biologists attempting to use his methods before 1925 frequently had difficulty in locating his contributions and even then the securing of some of the publications in which the articles appeared was not an easy matter. The worker who did not have access to one of the large university libraries was handicapped. The present volume overcomes this difficulty and doubtless will enable many workers to study a number of "Student's" contributions for the first time. Not only are all his published papers reprinted but numerous supplementary discussions of papers by other workers are given, including remarks made at meetings of biometricians. In short, we are now given "Student's" writings complete as a reference work, a fitting tribute to this hewer of a new pathway which has been broadened into an important road for those who must use small samples, as is true of many agricultural investigators. The publishers are to be commended for their efforts in producing a first-class example of printing and binding. (F. Z. H.)

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AGRONOMY AND HUMAN BEINGS[1]

F. D. KEIM[2]

TONIGHT we are assembled in the thirty-sixth annual meeting of the American Society of Agronomy. During the past 36 years American agriculture has gone through most of the trials and troubles that could confront a great democracy. We weathered a world war, enjoyed one of the greatest boom periods in history and suffered through a depression coupled with a terrific 10-year drouth that rocked the nation. Some scars remain but many lessons were learned.

Today we are again involved in a world war. Its requirements for food, man-power, and expenditures of public money make the last world struggle appear small. Through war and peace the American agronomist has played an important role and has tried to live up to the standards and ideals laid down in 1907 by the founders of the American Society of Agronomy.

Carleton (1)[3] in his presidential address in 1908 said of this organization, "The first association of the kind in America, and one that will have, without question, a tremendous influence on agricultural investigation and practice." Thorne (6) remarked in 1915, that, "The ultimate purpose of the work of the scientific agronomist is to increase the production of food and clothing for humanity." Jardine (2) wrote, "Men must be fed and clothed before they can fight. A continuous stream of food stuffs must be kept moving from this country and Canada to our allies and the allied armies at a time when not only is the world's available food supply low but the stores of wheat in Russia, India, and Argentina are inaccessible. Especially heavy, therefore, is the responsibility resting upon American Agriculture." This last quotation written in 1917 sounds so familiar that it could have been written in 1943.

There have been times during the past 36 years when the agronomist was accused of contributing too liberally to the food supply of the nation and agronomists, like many other scientists, were not in great demand. Today the world is again clamoring for more food,

[1]Presidential address delivered at the annual meeting of the Society in Cincinnati, Ohio, November 11, 1943.

[2]Chairman, Department of Agronomy, University of Nebraska, Lincoln, Nebr.

[3]Figures in parenthesis refer to "Literature Cited", p. 1001.

but sufficient agronomists and other thoroughly trained men are not available. As was the case during the last war, the agronomist has inventoried the seed supplies of the nation. He has headed campaigns for increased crop acreages. He has served on all kinds of committees that relate to food production and the war. The Society maintains an important committee on war and post-war adjustments. The 1942 report of this committee (4) is well worth rereading. The 17 recommendations made on the agronomist's position in the war and the post-war period are truly illuminating. In addition to these activities the agronomist is called upon for information on almost every conceivable point relating to agriculture, which he attempts to give through teaching, correspondence, public addresses, and the press.

The agronomist is not only thinking of the present emergency, but he is also looking forward into the future. He is contributing his full share to the conservation of the natural resources of the country so that human beings will continue to be sheltered, clothed, and fed. A strenuous effort is being made to increase production to the limit, but at the same time the agronomist hopes to avoid the dust storms and unnecessary erosion which followed as an aftermath of the last war and great drouth.

As is evidenced by the interest taken in nutritional research, he is not to be satisfied with providing food alone for humanity, but he is interested in the general field of nutrition and desires to supply the best of balanced rations. Again the agronomist expresses his interest in all those products that may be forthcoming from farm crops and thus increase their value and usefulness to industry and agriculture in the post-war period.

May I illustrate the importance of agronomic work to humanity by using an example from my own state. A like illustration could be taken from every state in the Union. During the past two years, the Nebraska Agricultural Experiment Station, with the cooperation of the U. S. Dept. of Agriculture, has thoroughly tested and made available for certification by the Nebraska Crop Improvement Association 21 new crop varieties. It has thus made these pure seeds available to the Nebraska farmer. These consist of Pawnee winter wheat; Otoe, Cedar, Fulton, and Trojan oats; Ezond barley; Dunfield and Illini soybeans; Ranger alfalfa; Lincoln bromegrass; Madrid, Spanish, and Evergreen sweet clover; Biwing flax; and seven corn hybrids, U. S. 13, U. S. 35, Illinois 201, Indiana 608C, Iowa 4059, Iowa 306, and Ohio 92. If these are added to some 20 other crop varieties that previously have been made eligible for certification, the Nebraska farmer has a large number of superior crops from which to choose.

It is worthwhile to consider just what these choice varieties of farm crops mean to the wealth of the state in which they are released. Increase in yields alone, to say nothing about better quality of these highly selected crops over the old original varieties, will range from 10 to 20%. This means 10 to 20% more cash grain and 10 to 20% more grain, hay, and forage to feed the livestock of Nebraska. Since nearly every state can show much the same ac-

complishment along this particular line, the cash grain and feed made available by this experimental work is tremendously important any time and especially in the war emergency.

Two specific examples will suffice to make more clear what this means to our wealth. Pawnee wheat is the result of a Kawvale × Tenmarq cross made at the Kansas Agricultural Experiment Station. One hundred and thirty-eight plant selections were obtained by the Nebraska Agricultural Experiment Station from among which Pawnee was finally selected. At Lincoln for seven years (1936–1942) Pawnee has had an average yield of 28.4 bushels per acre compared with 21.8 for Turkey, an increase of 6.6 bushels per acre. This wheat is especially adapted to the southeastern part of Nebraska where farmers annually grow at least 1,000,000 acres. If all farmers, in this area planted Pawnee, total wheat production would be increased approximately 6,600,000 bushels. At $1.25 per bushel this would add to the wealth of the area 8¼ million dollars.

From a mere beginning in 1933, hybrid corn now dominates corn production in the United States. In 1943 approximately 50 million acres, nearly 52% of the total corn acreage of the country, was planted to hybrid seed. This represents our best corn land and probably produced at least three-fourths of the entire crop. Calculating on a basis of 20% increase due to hybrid development, the total production of corn in the United States has increased approximately 375 million bushels. Such accomplishments, reaching their xenith just at this time, make it possible to meet the unprecedented demands of supplying food and clothing to our Allies as well as adequately providing for our own people.

There could be many more similar examples. Richey (5) in his presidential address in 1937 entitled, "Why plant research?", covered many of them very thoroughly. I should like to mention a few research projects and accomplishments that seem to me to be of great significance, as follows: (a) The possibilities along the line of native grass seed collection, production, and processing, and the cultural practices necessary to re-grass non-crop lands; (b) adaptation to local conditions of strains of bromegrass and other cultivated and native grasses; (c) vegetation surveys and practical applications made in range and pasture management; (d) use of grasses in rotation in semi-humid to semi-arid regions and their effect on production, erosion, soil tilth, and other farm management practices; (e) the development of hybrid alfalfa, bromegrass, and other distinct plant improvement through breeding; (f) advances in the knowledge and dissemination of this knowledge on perennial weed eradication and control methods; (g) the manufacture, methods of application, and use of fertilizers adapted to the many soil types and conditions in the United States; (h) the tremendous growth of soil conservation districts in the nation and the advance in good farm management practices and land utilization that are accruing from these operations; (i) and finally the wealth of technical research that contributes to the knowledge of fundamental physical, chemical, and biological science. One could continue at length citing research results and the needs that lie ahead, but there is another phase of

this subject of agronomy as it relates to human beings that always has been a hobby of mine.

Two important opportunities confront every department of agronomy. First, there is the training of outstanding men for teaching, research, and other agronomic activities. Second, there is the completion and publishing of essential and valuable research results. It is the quality and quantity of the results of these two functions that determine the national rating of any department. The second function, quality and quantity of research, has been considered briefly earlier in this discussion. It is my desire now to direct attention to the training of good men.

I honestly think that college and station agronomists in most of the states have given this subject a great deal of thought. The general level of agronomic personnel over the country has made a phenomenal improvement. Most modern agromonists have appreciated the value of the fundamental sciences, such as chemistry, physics, mathematics, geology, and all the branches of biological science, in solving their problems. Students soon recognize this and the cream of the crop naturally gravitate into this type of intellectual atmosphere. In order to facilitate such a migration, it is necessary to have outstanding teachers for freshmen and undergraduates. These teachers do not need necessarily to be great research workers, but they must have this fundamental science knowledge and be able to instill its need into the minds of their students. Much has been written on this subject. In 1937 I (3) discussed the agronomy teacher and his training at some length. I feel now more than ever that a very great responsibility rests upon the shoulders of the undergraduate teacher. It is he who will choose and do much of the training of the embryonic agronomists. He must recognize early the student with outstanding ability. It is in the upper 5 or 10 among 100 students where the teacher is most likely to find the scholarly man whom he should encourage to continue in training and go into the profession. This scholarly young man should not be an oddity. It is preferable that he be normal in size, of good appearance, and have high personal quality. He should show signs of leadership and be able to get along with his associates and others with whom he comes in contact. He should have unusual capacity for hard work and show early in his career the capacity for completed accomplishment.

A characteristic that is frequently overlooked in choosing the prospective agronomist is the quality which the student possesses of noting the value of little things. If a young assistant can sense the presence of angoumois moths, mice, and other laboratory pests and remove the source without being told; if he has a knack of cleanliness about the teaching or research laboratory; if he handles the departmental cars, trucks, and other equipment in peace times as war time demands—he has something that will make him valuable to any department in which he may later be employed.

A few years ago I was watching a farmer's fair parade staged by the students of the Nebraska College of Agriculture. Numerous tractors and trucks were being driven by these students. On one of the drives a fair sized hole had been previously worn in the pave-

ment. It had rained and this hole was full of muddy water. Driver after driver hit this hole with one of the tractor wheels. Occasionally a few of the drivers would make an effort to avoid hitting the hole. In every case where this effort was made an outstanding student was at the wheel. This, of course, is a minor thing, but it does show a quality of carefulness and thoughtfulness that is important.

The undergraduate teacher has a real responsibility in administering a college curriculum. Unless he has a thorough knowledge of the contents of courses in his own field and a wide knowledge of supplementary courses necessary to round out the training of this young student, the time will come for graduation and much-needed training will be missing. I thoroughly agree with Throckmorton (7) that too much early specilization in a student's career should be avoided, and that basic courses in the sciences related to agriculture are very important. Nevertheless, it is amazing how many different lines of opportunities are developing for agronomy majors. It seems to me that to best prepare a student for one of these special opportunities, the fundamental and specialized training must differ materially.

Many times I have attempted to arrange a curriculum that would offer the best training for the various agronomy lines such as the soil chemist, soil bacteriologist, soil physicist, soil surveyor, soil conservationist, the plant breeder, technical geneticist, range examiner or surveyor, land appraiser and farm manager, food and feed processor, hybrid corn production manager, seed certification manager, county agent, extension agronomist, the college teacher, and the so-called scientific farmer. I admit that the first two years of the curriculum should remain much the same, but the junior and senior years differ rather widely. This is not due entirely to the training needs of the student for these various lines of work, but partly because young men differ so much in temperament and aptitudes. If they can be directed to the proper niche and assigned courses of study that coincide with their desires, their chances of success are infinitely better. It takes a wise undergraduate teacher to sift young men into these different categories and plan their schedules accordingly. It takes patience and long hours of after-class discussion, but it is worth while.

I have seen students flounder for months trying to decide on just what line of agriculture they wished to follow. Many times I have asked them this question, "If you had your choice of all the jobs in the world just what would you choose?" Frequently this question crystalizes their thinking and before long they are able to make rather definite decisions. I also try to assure them if they do a good job in whatever they undertake, other things are more likely to work out, so that too definite choice is not necessary.

I remember one amusing case. This young man was a brilliant student and possessed a personality that would take him anywhere. He tried soils and then genetics but he did not click. He received his degree but as a scientist he was impossible. When he graduated, an opportunity came along as a salesman for a large chemical and insecticide concern. He took it rather reluctantly. In less than a

month he was perfectly contented and bubbling over with enthusiasm. He had finally found his niche.

The undergraduate teacher has the responsibility of selling himself and his product and the finest incentive for knowledge is a feeling of the need of that knowledge. Do we as teachers point out this need to the student as much as we should? Too many teachers throw a subject at a student without pointing out the wonderful possibilities that will accrue if proficiency is attained.

It is difficult at times for the full-time research man to realize the value of apprentice training for graduate and undergraduate students. The earlier a young man who shows the proper caliber for an agronomist can be used as a student assistant in teaching or experimental work, the broader will be his knowledge when he receives his degree. Here again patience and an aptitude on the part of the teacher or research worker for training these young men should be encouraged. If the man in charge of a project is a lone wolf and does not have this aptitude, it will probably be better not to assign younger students to him for part-time work.

The young agronomist should be encouraged to become really proficient in English. His ability to express himself before the public, in the writing of research papers and the many popular articles and letters which he will be called upon to write, will be a great satisfaction to him and to the department which he represents.

Attendance at conferences and other scientific group meetings for both graduate students and faculty should be encouraged. The progress of research in many special fields has advanced with rare rapidity due to such conferences. Months of time can be saved by the exchange of ideas. The general knowledge and presentation of subject matter and the acquaintance made with colleagues makes meetings and conferences of untold value to the student and research representative.

There is one other phase in the training of this agronomy student that I want to emphasize. It is probably more important than the academic training. This is the moral and character-building qualities that he should develop in his life. Here the teachers again play an important role. I recently made this statement in regard to the late Dr. A. L. Frolik, "Frolik believed that every teacher should be a living example of all character-building principles. His popularity, enthusiasm, and salesmanship caused most of his students to copy these high standards and build them into their lives."

Recently, Dr. T. H. Goodding and I checked back over 54 students making up our Nebraska crop judging and identification teams. Only 3 of the 54 who participated in the activity were addicted to the usual forms of intemperance. Moderation is the key word of character. I am interested in the student who believes in temperance in word and act; who does not indulge in too much drinking, if any, of course, but equally never too much eating, scolding, laughing, dancing, smoking, reckless driving—never excess at all. This quality gives a student a freedom that often accelerates his progress, and still more important, it is an indication that he possesses the fine quality of self control. Another indication of the

character-building qualities of the student is his religious activity. Leadership in church activity is almost sure to add to a student's value during the time he is in school and after he gets out on the job. The communities that make up the world need this kind of leadership, and the agronomist should contribute his bit. If our profession is to wield its influence on humanity to the greatest possible degree, no aspect of character and leadership can be overlooked in training the young agronomist. A department or institution can not be any greater than the men and women who make up its personnel.

The fruits of research and teaching must be translated eventually into action on the farm and in industry. Unless this is done the work of the agronomist as such will have been in vain. To speed this translation into action the extension agronomist plays a prominent part. In training future agronomists this service and activity should receive as much attention as any other.

The end of all research, teaching, and extension in agronomy is to improve the status of agriculture and to provide human beings with an abundance of farm products of the most acceptable kind and quality, at a minimum cost. In other words, we agronomists have the job of doing our share to see that people have an opportunity to live better in a better world.

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THE SORPTION-BLOCK SOIL MOISTURE METER AND HYSTERESIS EFFECTS RELATED TO ITS OPERATION[1]

L. A. RICHARDS AND L. R. WEAVER[2]

DAVIS and Slater (1)[3] in a note to this JOURNAL described a "direct weighing method for sequent measurement of soil moisture under field conditions". Independently the authors have been working on a moisture meter using the same principle and, although our results are not complete or conclusive, all the information we have obtained appears to be favorable to the method. Since our work on this project has been interrupted by the war, it is the purpose of this paper to report the progress we have made.

The method is based on the fact that a suitably disposed porous block will sorb (sorbeo—to suck in) moisture and come to equilibrium when placed in contact with moist soil. The rate at which equilibrium is attained and the degree of correspondence between the weight of the sorption-block and the moisture content of the soil are pertinent to the success of the method.

APPARATUS

Of the various forms of the apparatus tried by the authors, that shown in Fig. 1 appears to be the most promising. A piece of tubing (A) inserted in the soil serves as the mounting for the system.[4] The soil surface at the bottom of the tube is leveled, packed gently, and covered by a disc of long fiber asbestos paper (B) which is cemented to the top of a short section of thin-walled brass tubing (c). This asbestos (0.008 inch thick) should be washed in water to remove sizing material. Three short legs of copper wire (D) soldered to the inside of the ring help to keep the asbestos cover in place. The sorption block (E) consists of a short cylinder of porous ceramic material mounted on a brass pin and covered with a disc of mica. We have used 36 gage copper wire rolled to a ribbon for the suspension.

A No. 5 rubber stopper (F) is mounted on the end of a section of steel tubing (G) (3/8 inch outside diameter, $\frac{1}{32}$ inch wall). A washer is soldered on the tube to transmit the thrust to the stopper. The rubber stopper serves the double purpose of making a vapor seal to the sorption block chamber and also supplies a continuous elastic force to hold the block in contact with the soil when the small tube is lowered and clamped in place by the set screw in the threaded

[1]Contribution from the U. S. Regional Salinity Laboratory, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Riverside, California, in cooperation with the eleven western states and the Territory of Hawaii. Received for publication June 2, 1943.

[2]Senior Soil Physicist and Agent, respectively. The authors are indebted to P. E. Skaling for assistance with the experimental work on this project during the spring and summer of 1941.

[3]Numbers in parenthesis refer to "Literature Cited", p. 1011.

[4]We have used 1-inch thin-walled steel electrical conduit tubing. The inside of the lower end must be polished and carefully coated with tin or solder to prevent corrosion. The rest of the interior should be freed from burrs and coated with waterproof paint.

collar. A disc of mica (H) supports the upper end of the suspension and also helps to exclude extraneous material from the sorption block chamber. The turned wood cap (I), which is impregnated with paraffin, forms a closure for the top of the system and has a felt insert (J) to make a dust seal.

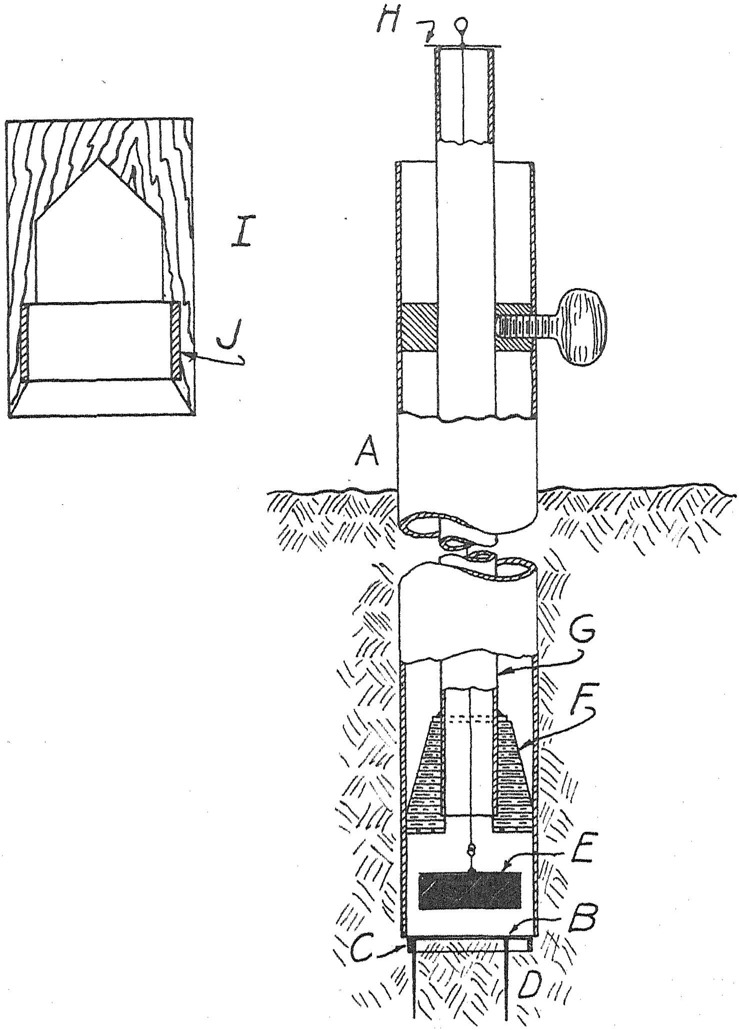

FIG. 1.—Sorption block assembly for a soil moisture meter.

We have used sorption blocks ¾ inch in diameter and ¼ inch thick which were plaster cast from a slip made from 90% common brick earth and 10% diatomaceous earth. After drilling holes for the brass pins, the blocks were brought to 850° C in an electric muffle furnace

and allowed to cool. Abrasion of the blocks during handling was effectively prevented by lightly vitrifying the peripheral surface with an acetylene torch.

The sorption block weighings can be quickly made. The procedure is simply to (a) remove the wood cap, (b) unclamp the set screw and raise the rubber stopper (shown in the raised position in Fig. 1) and, (c) mount the weighing device on the top of the tube and attach the suspension system.

EXPERIMENTS

A preliminary experiment was set up in a constant temperature room (21° ± 1.0° C) to get information on the rate of transfer of water between sorption blocks and soil. Four 4-gallon crocks were filled with Fallbrook loam at four different moisture contents ranging from 15-atmosphere-percentage (near the wilting percentage) to the third-atmosphere-percentage (near the moisture equivalent). The soil for the crocks at low moisture levels was thoroughly mixed during and after wetting and was packed to field density. Three sorption block tubes were installed in each crock, the soil surface was heavily sealed with paraffin, and the pots were allowed to stand several weeks to approach equilibrium before experiments were started. The sorption-block installations were similar to those shown in Fig. 1. An analytical balance supported on a track was used for the weight measurements and weighings were made to 0.1 milligram. Lack of change of weight of each sorption block was considered indicative of equilibrium between block and soil.

Results from a considerable number of measurements may be summarized as follows:

1. Blocks saturated with water come to constant weight in wet soil in less than a day.
2. Dry blocks come to constant weight in wet soil in less than 3 days.
3. Wet blocks come to constant weight in dry soil in less than 5 days.
4. Blocks transferred between adjoining moisture levels either wetter or dryer generally reach equilibrium within 2 days.
5. For blocks having the composition given above there was found to be a hysteresis effect. That is, the equilibrium weight of a given block in a given soil depended on whether the block initially was wet or dry. This hysteresis effect was largest in wet soil. If the variation in the weight of the block from saturation to the wilting condition is taken as 100%, the block weight at equilibrium in wet soil (½ atmosphere tension) was found to vary through approximately 4% of this range, depending on whether equilibrium was approached from the wet or the dry side.

SORPTION-BLOCK OPERATION UNDER PLANTS

Sorption-block assemblies like those shown in Fig. 1 were installed at a depth of 6 inches in 4-gallon crocks containing Fallbrook loam. The crocks which were planted to maize and placed in the greenhouse are shown in Fig. 2. Block weight readings were taken usually just once daily between 8 and 9 o'clock in the morning. Fig. 3 shows

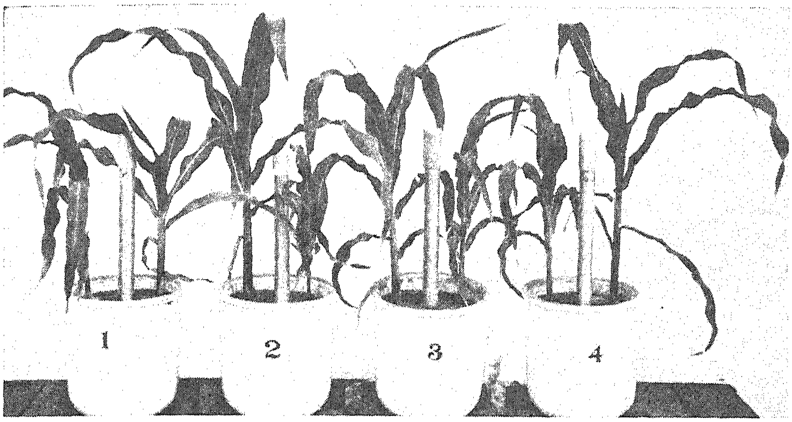

FIG. 2.—Sorption-block moisture meters in greenhouse pots. The photograph shows the condition of the maize on July 21, one day after irrigation.

the gross weight vs. time curves for these four moisture meters. When the plants were badly wilted, enough water was applied to the pots to produce some drainage outflow. The open circles on the curves indicate the day on which the plants developed wilting symptoms before noon. Fig. 2 shows the condition of the plants on July 21, one day after irrigation. It is seen that block weight corre-

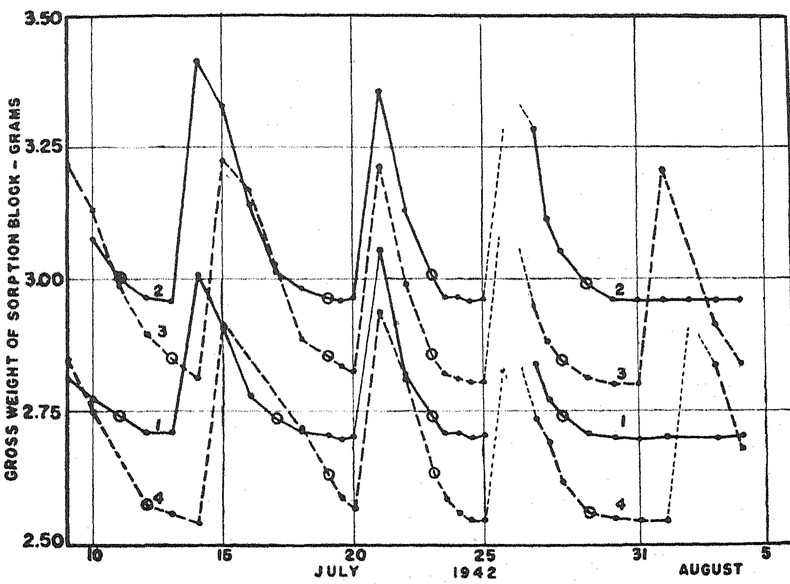

FIG. 3.—The variation of sorption block weight with time. The blocks were installed at a depth of 6 inches in four soil pots in which maize plants were grown. The open circles on the curves (one curve for each pot) indicate the days when wilting occurred before noon.

lates nicely with wilting, the variations in the weight of a block at the successive wiltings being generally less than weight losses during one day's time. There is reason to believe the blocks were not lagging far behind the soil even under these conditions of rapid soil moisture extraction. It is seen further that after permanent wilting the block weight soon attains a minimum value and that this minimum is the same for subsequent dryings. For the sorption blocks used in this experiment this minimum weight was not far above the oven-dry weight so these blocks were not suitable for studying moisture losses in the wilting range. Gross pot weight readings were not taken so the relation between block weight and soil moisture content was not established, but the curves in Fig. 3 resemble weight loss curves for soil pots containing plants (7).

It is seen that the range of moisture change for the blocks used is 300 to 400 milligrams. The gross weight of these blocks and suspension systems was kept small because the weight readings were made with a low capacity spring balance[5] free from the thermal effects. The authors have not studied the weighing problem sufficiently fully to make recommendations on a weighing device for general field use, but this appears to be only an incidental technical problem. In the future we plan to use sorption blocks about 3/8 inch thick.

HYSTERESIS

In the absence of temperature gradients it appears that gravity and gradients in the equivalent negative pressure or soil moisture tension are chiefly responsible for the movement of water through soil and hence into and out of sorption blocks. The relation between the soil moisture content and soil moisture tension for the block and the soil is thus of some interest.

It appears to be well established experimentally that there is a hysteresis effect in the relation between soil moisture tension and moisture percentage (4). This is indicated by the moisture content differences found at the same tension for various soils as shown in Table 1. Fig. 4 is a graphical representation of the data for the Yolo fine sandy loam. The soils are surface samples, 0 to 6 inches, and the series names were taken from the soil maps. The Vale sample is from plot B of the alkali experimental plots of the Oregon Agricultural Experiment Station at Corvallis.

These results were obtained with 6-inch double-walled irrigator pots by a method which has already been described (4). The experiment was conducted at a temperature of $21 \pm 1°$ C and the equilibrium moisture content of the soil for the successive soil moisture tension values was calculated from the initially determined tare weight and the successive equilibrium gross pot weights. The soils were screened and packed in the pots at approximately field density. The initial moisture content and the date of starting of the experi-

[5]The spring was the Isoelastic type manufactured by John Chatillon Company. It was 0.32 cm in diameter and 12.5 cm long, with a spring constant of 5 cms per gram. A conventional jolly balance mounting was used and weighings could be quickly made to within ±2.5 milligrams. The authors have also used inexpensive jolly balance springs, but these are subject to temperature effects for which we did not wish to make adjustments in this preliminary work.

TABLE 1.—*Hysteresis data for six soils from western United States.**

Equilibrium attained	Fallbrook loam S-40-1			Ritzville loam S-40-18			Yolo fine sandy loam S-40-23			Indio very fine sandy loam S-40-4			Vale plot B S-40-16			Imperial clay S-40-3		
	Date	Tension	Pw	Date	Tension	Pw	Date	Tension	Pw	Date	Tension	Pw	Date	Tension	Pw	Date	Tension	Pw
Start	Mar. 12, '41	—	4.17	Mar. 11, '41	—	2.14	Mar. 11, '41	—	9.02	Mar. 11, '41	—	5.37	Mar. 12, '41	—	12.40	Mar. 12, '41	—	9.34
1	June 12	610	5.23	July 10	610	10.20	July 10	610	17.16	Aug. 5	609	12.49	July 10	610	21.28	June 12	610	28.28
2	Aug. 18	305	5.86	Oct. 27	306	13.14	Sept. 30	304	19.10	Sept. 30	305	14.65	Sept. 30	304	23.90	Aug. 18	305	29.71
3	Jan. 7, '42	152	7.75	Feb. 20, '42	153	19.60	Dec. 23	154	22.00	Dec. 23	153	18.50	Dec. 23	153	27.97	Oct. 15	153	31.89
4	Feb. 20	2	23.05	Mar. 20	0	39.01	Feb. 20, '42	0	42.39	Feb. 20, '42	0	40.09	Feb. 20, '42	0	48.47	Jan. 7, '42	0	52.31
5	Mar. 25	153	14.44	Mar. 25	153	33.47	Mar. 20	152	25.47	Mar. 20	153	28.62	Mar. 19	153	34.17	Feb. 20	152	35.24
6	Apr. 1	306	8.54	Apr. 1	305	18.53	Mar. 24	305	22.46	Apr. 20	306	24.05	Mar. 25	305	29.37	Mar. 20	305	32.83
7	Apr. 17	610	6.02	Apr. 17	611	12.77	Apr. 1	610	19.82	May 5	610	21.42	Apr. 1	610	24.96	Apr. 1	610	30.69
8	Apr. 27	774	5.55	Apr. 27	775	11.60	Apr. 11	776	18.64	May 29	777	19.22	Apr. 8	777	23.27	Apr. 8	776	29.79
9	May 3	611	5.63	May 12	611	12.15	Apr. 27	611	18.72	June 10	610	18.63	Apr. 17	611	23.61	Apr. 24	614	29.90
10	May 12	306	6.53	May 25	307	15.05	May 5	305	20.24	June 20	306	19.14	Apr. 22	306	26.08	May 5	305	30.95
11	May 25	153	10.27	June 15	153	21.80	May 18	154	22.80	June 26	152	19.90	Apr. 27	153	30.15	June 2	1	45.58
12	June 10	1	20.06	July 8	0	33.91	May 29	305	20.97	July 8	0	33.40	May 5	0	42.56	June 10	152	33.92
13	June 20	153	13.34	July 22	153	26.72	June 10	610	19.10	July 22	152	25.83	May 12	153	31.99	June 20	305	32.04
14	July 1	306	7.63	July 27	304	17.91	June 20	776	18.60	Aug. 3	306	23.12	May 18	306	27.87	July 1	612	30.09
15	July 8	612	6.14	Aug. 3	613	12.88	June 24	611	18.68	Aug. 10	611	21.59	July 8	777	23.17	July 8	777	29.64
16	July 15	781	5.63	Aug. 11	775	11.96	July 8	306	20.17	Aug. 20	776	20.07	July 15	610	23.36	July 15	611	29.75
17	July 22	610	5.74	Aug. 16	612	12.33	July 15	610	18.95	Aug. 26	610	19.64	July 22	305	25.79	July 22	296	30.84
18	Aug. 3	305	6.73	Aug. 22	306	15.38	July 22	776	18.49	Aug. 30	307	19.86	July 29	153	29.93	July 31	154	32.49
19	Aug. 10	153	10.23	Aug. 28	154	21.76	July 27	610	18.60	Sept. 2	152	20.32	Aug. 8	0	41.54	Aug. 8	0	44.15
20	Aug. 22	0	19.59	Sept. 4	0	32.40	July 31	307	19.75	Sept. 4	0	31.12	—	—	41.4†	—	—	43.7†
21	—	—	19.6†	—	—	32.6†	Aug. 10	153	22.49	—	—	30.5†	—	—	—	—	—	—
22	—	—	—	—	—	—	Aug. 22	0	36.75	—	—	—	—	—	—	—	—	—
23	—	—	—	—	—	—	Aug. 26	152	24.17	—	—	—	—	—	—	—	—	—
24	—	—	—	—	—	—	Aug. 30	306	21.54	—	—	—	—	—	—	—	—	—
25	—	—	—	—	—	—	Sept. 3	776	19.02	—	—	—	—	—	—	—	—	—
									18.6†									

*Soil moisture tension is expressed in cm of water. Pw is grams of water per 100 grams of dry soil.
†Check value of Pw determined by drying at the termination of the experiment.

ment are given in the first row of data in Table 1. The successive dates for the successive equilibria are also given. In many cases the pots were allowed to stand longer than was necessary to attain equilibrium, but from intermediate gross pot weight readings it was made certain that equilibrium was attained before the tension

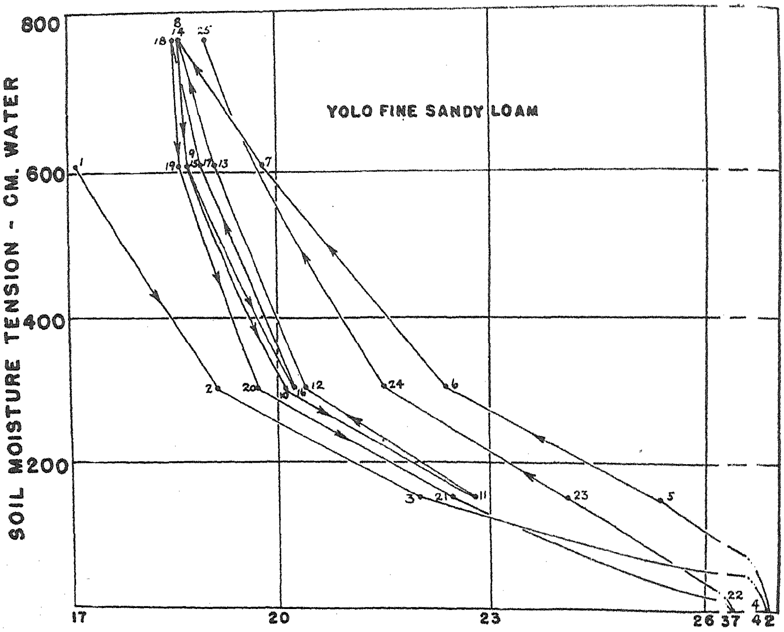

FIG. 4.—Curves showing equilibrium moisture sorption data for Yolo fine sandy loam. The numbers on the curves indicate the chronological order in which the various equilibria were obtained.

changed.[6] At the end of the experiment the moisture percentage was determined by drying as a check against the value calculated from the gross pot weight. These check values are given at the bottom of the moisture percentage columns. The soil moisture tension is given as the distance from the center of the soil mass (approximately 2.5 kilos) to the free water surface in the supply reservoir. This distance seldom varied more than ± 2 cm from the desired value.[7]

[6]It will be noted that for equilibria following 9 and 17 for the Indio soil, a decrease in tension resulted in a decrease in the moisture content. This is inconsistent with all past data and throws some doubt on whether points 9 and 17 were actually equilibria points.

[7]Table 1 gives the average moisture content and the average soil moisture tension in the soil mass, but because of the height of the soil column (18 cm) there is a tension difference at each equilibrium of 18 cm of water between the top and bottom of the column and at low tensions this results in a very appreciable moisture content gradient. Small changes in the level of the water in the supply reservoir at the zero tension setting produce corresponding changes in the water table in the soil pot with consequent large changes in the calculated (average) moisture percentage. This fact accounts in large part for the spread in moisture content values at zero tension.

As has been indicated by Haines (2) and by S. J. Richards (3) for sands, it is apparent from Fig. 4 that equilibrium between soil moisture tension and moisture content can be attained at any point within the hysteresis loop. Thus, any method for estimating soil moisture content that is based on a soil moisture tension measurement will involve an uncertainty as large as the width of the hysteresis loop, unless something is known of the moisture history of the soil. However, the amount of hysteresis found for the soils in Table 1 is probably considerably larger than occurs for these soils under field conditions. It is not known, for instance, to what extent the difference between the initial and subsequent wetting curves is due to the structural change occurring during the first wetting. Also, field experience and the time required to obtain the first three equilibrium points for the soils in Table 1 indicate that seldom is any appreciable fraction of the soil profile in the moisture states represented by the left hand curve in Fig. 4. On the other side of the hysteresis loop it will be noted from the data in Table 1 that the extreme curve is usually connected with the highest moisture content attained in wetting. Field experience with tensiometers indicates that seldom are well-drained soils beneath the surface few inches wetted to zero tension, even under basin irrigation. A hysteresis loop such as represented by points 9, 10, 11, 12, and 13 is more commonly to be expected in the field. Furthermore, as indicated by the data in Fig. 3, if the soil moisture is replenished with an ample application of water, the wetted part of the profile will exist in moisture states represented by drying (desorption or moisture retention) curves most of the time. For the extreme case, when the soil moisture fluctuates between fixed limits, the moisture regime will be represented by a single drying curve.

Little information seems to be available on hysteresis effects in porous media having fixed structure. Our experiments indicate, as would be expected, that the effect does exist and it appears that this should be an advantage rather than a disadvantage in the operation of sorption-block moisture meters. Hysteresis in the block will be in the same phase as hysteresis in the soil and hence will make the block weight more nearly correspond to soil moisture content.

DISCUSSION

At equilibrium the soil moisture tension in a sorption block approaches equality with the tension in the contiguous soil. For agricultural purposes the most useful information that can be obtained from readings with a sorption-block soil moisture meter would be (a) an indication of the rate and time of approach to the wilting condition, and (b) an indication of the amount of available moisture present in the soil, expressed either as volume of water per unit depth of soil or as a fraction of the available range for the soil.

Recent experiments at this laboratory (5, 6) indicate that the first of these objectives can be achieved with sorption blocks. Readings for a series of sorption-block installations can be quickly interpreted if the blocks are tared so as to have the same weight at the wilting

condition. To attain the second objective may require the selection of sorption blocks with a moisture retention characteristic related in a fairly definite way to the characteristic curve for the soil. This, however, should not be difficult to do.

When the U. S. Weather Bureau was first established to obtain information of use to farmers, the moisture reserve in the soil was proposed as one element in the crop environment to be widely measured and reported. The difficulties encountered did not make this feasible. For such purposes as crop yield forecast, a representative indication of moisture reserves available in the soil for maturing a crop would be useful and the sorption block moisture meter may prove suitable for this kind of work. A more immediate and practical application, of course, would be its use as an aid in soil moisture control under irrigation.

As Davis and Slater (1) have indicated, the sorption-block type of moisture meter makes possible the "sequent measurement" of moisture changes at a given location which is of particular advantage in following continuously the depletion of available moisture. When properly built, these units should require little servicing or attention and accurate results should be immediately obtainable even with long periods of neglect or elapsed time between readings. The units are not susceptible to frost injury or to disturbances from salt effects in soils. This latter feature is of considerable importance to the work of the Salinity Laboratory where the moisture regime of plants in saline and alkali soils is under study. The authors are inclined to favor ceramic sorption blocks, thus avoiding troubles that may arise from the solubility and low mechanical strength of gypsum.

The temperature of the sorption block, as well as the temperature of the adjacent chamber and soil, should be representative of the surrounding soil so as to prevent condensation in the sorption block chamber and to prevent moisture gradients in the soil adjacent to the block which might arise in response to temperature disturbances introduced by the tube. We have used steel tubing in our units. This may be expected to give trouble with shallow installations, especially where the temperature of the exposed part of the tube differs considerably from the soil temperature. We have not made a careful study of temperature disturbances, but for installations at a depth of 6 inches in greenhouse pots (Fig. 3), data for morning and evening readings lie on a smooth curve.

Experiments should be conducted to determine the characteristics of porous ceramic material best suited for sorption block use and to determine more precisely what correspondence there is between block weight and soil moisture content for various wetting and drying rates and limits. We have used the pressure-membrane apparatus for obtaining the moisture retention curves for various porous ceramic materials, but this work has not proceeded far enough to make specific recommendations. It appears that a reasonably satisfactory test of the relation between sorption block weight and moisture content can be made in soil pots containing a uniformly distributed plant root system. Under proper conditions the moisture

throughout the pot is depleted fairly uniformly and the soil moisture content at the block can be inferred from the gross pot weight.

SUMMARY

A porous ceramic block if protected from evaporation will come to moisture equilibrium with soil with which it is in contact. A description is given for a sorption-block soil moisture meter based on weighing the block while suspended in the soil, thus avoiding exposure to evaporation. Various tests made indicate that this type of apparatus can be used for measuring the condition and amount of moisture in soil.

Data on the hysteresis effect for six soils are given. The occurrence of hysteresis in ceramic sorption blocks is noted, and this, being in phase with that of the soil, should improve their action for measuring soil moisture.

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MINOR ELEMENT STUDIES WITH SOYBEANS: I. VARIETAL REACTION TO CONCENTRATIONS OF ZINC IN EXCESS OF THE NUTRITIONAL REQUIREMENT[1]

E. B. EARLEY[2]

THERE is usually considerable variation among plant varieties of a given species in reaction to temperature (6, 8, 10, 15),[3] drought (5, 16), disease (1, 9, 19), insects (3, 12, 13, 17), etc. It is likewise known that plant varieties react differently in the absorption and metabolism of at least some of the chemical elements. Such varietal differences have been noted by Anderson and Ayre (2), Burkholder and McVeigh (4), and Hoener and DeTurk (11) for nitrogen; by DeTurk, *et al.* (7), Lyness (14), and Smith (18) for phosphorus; by Weiss (20) for iron, and by Allen[4] for several of the major elements. Yamasaki (21) observed the differential behavior of rice and wheat varieties to copper sulfate, sodium arsenate, zinc chloride, mercuric chloride, potassium dichromate, potassium cyanide, potassium perchlorate, potassium iodate, potassium bromate, and potassium and sodium chlorate. From his experiments, he concluded that definite varietal distinctions existed only with respect to the chlorates and that the basis for this distinction is the differential ability of the plants to reduce the nontoxic chlorate ions to the toxic hypochlorite ions.

With reference to the effect of the other chemicals tested for varietal reaction, Yamasaki (21) stated that, "All of the salts tested other than the chlorates, $KClO_3$ and $NaClO_3$, injured the seedlings very seriously as a whole but never showed the varietal distinctions as observed in relation to $KClO_3$." This statement is believed by the writer to be unjustified on the basis that Yamasaki correlated the results of an experimentally determined concentration of $KClO_3$ (0.2%) with those from an equal concentration of $ZnCl_2$, and concluded therefrom that the latter was incapable of inducing varietal distinction. Had he experimented as thoroughly with different concentrations of the other salts as he did with the chlorates, he probably would have discovered that varietal distinction to direct toxicants[5] is a matter of salt concentration rather than salt specificity.

The purpose of this paper, therefore, is to call attention to the

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[1]A contribution of the former U. S. Regional Soybean Industrial Products Laboratory, Urbana, Ill., a cooperative organization participated in by the U. S. Dept. of Agriculture and the agricultural experiment stations of the North Central States of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. Received for publication May 1, 1943.

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[3]Figures in parenthesis refer to "Literature Cited", p. 1022.

[4]ALLEN, DENVER I. Differential growth response of certain varieties of soybeans to varied mineral nutrient conditions. Unpublished doctor's thesis, University of Missouri. 1941. Copy on file Department of Agronomy, University of Missouri, Columbia, Mo.

[5]Those salts whose toxicity to plants is independent of chemical change are termed direct toxicants.

varietal reaction of soybeans to zinc and to show the magnitude of the difference between the most susceptible and resistant varieties studied.

EXPERIMENTAL RESULTS

The effect of zinc on the growth of soybean plants was observed in the greenhouse during the fall of 1937. At that time an alloy pump, later found to be 95% zinc, was used to pump the nutrient solution into crushed quartz in which the plants were growing. The composition of the nutrient solution in which the zinc toxicity symptoms first appeared was as follows:

Elements	N	P	K	Mg	Ca	S
Parts per million	84	62	156	48	120	64
Millimoles	6	2	4	2	3	2

Salts	Moles
KH_2PO_4	.002
KNO_3	.002
$Ca(NO_3)_2 \cdot 4H_2O$	.002
$CaCl_2 \cdot 2H_2O$	.001
$MgSO_4 \cdot 7H_2O$	.002

Also 0.06 p.p.m. of Cu as $CuSO_4 \cdot 5H_2O$; 0.5 p.p.m. of B as H_3BO_3; 0.5 p.p.m. of Mn as $MnCl_2 \cdot 4H_2O$ and 2.0 p.p.m. of iron as $FePO_4 \cdot 2H_2O$

When about 3 weeks old, the plants developed symptoms similar to those shown in Fig. 1. These symptoms, in approximate order of appearance, consisted in the incipient formation of a red pigment at the base of the central leaf vein, the curling under of the leaves, chlorosis of the trifoliate leaves near the growing point of the stem, a dying of the apex of the stem, and an intensification of the red pigment in the leaf veins, petiole, and stem. A slight increase of manganese and boron as well as the addition of iron as ferric chloride did not alleviate the condition of the plants, whereas an increased pH brought about considerable improvement.

COMPARATIVE EFFECT OF ZINC NITRATE AND DISSOLVED ZINC-ALLOY PUMP ON GROWTH OF HUDSON MANCHU

From the results of the above experiment it was hypothesized that enough zinc was being dissolved from the zinc-alloy pump to injure the plants. This idea was tested by making a dilute hydrochloric acid solution of the pump, of known concentration, and comparing its effect upon plant growth with that of an equal concentration of zinc nitrate solution. In this experiment seven bottles were used, each containing 18 liters of a standard nutrient solution. These consisted of a check bottle receiving no zinc and two sets of three bottles each, with one set receiving 1, 2, and 4 p.p.m. of zinc as alloy pump and the other set receiving the same concentrations of zinc as zinc nitrate. Each bottle supported four plants, two Hudson Manchu and two Peking.

Identical symptoms were produced in the plants by the two solutions. This fact, therefore, confirmed the above hypothesis that zinc from the nutrient solution pump caused the death of the soybean plants. The photographs in Figs. 2 and 3 show the similarity of reaction of Hudson Manchu plants to zinc from these two sources.

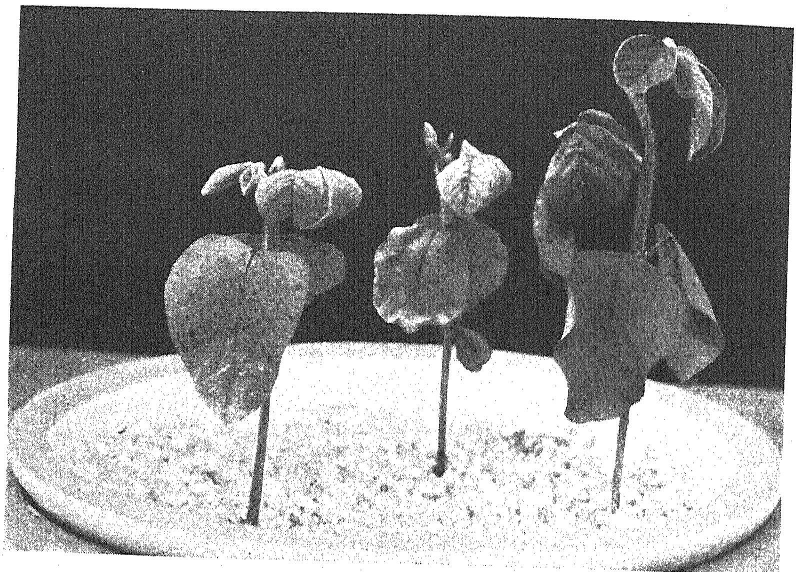

FIG. 1.—Boone plants exhibiting typical zinc toxicity symptoms. They were produced as the result of burying one-half of a zinc alloy pump in the crushed quartz. Planted April 23, 1938; photographed June 7, 1938.

The effect of zinc from the alloy pump casting and of zinc nitrate on root formation of the Hudson Manchu variety may also be observed in Fig. 4. As much as 1 p.p.m. of zinc in either of the above forms appeared to have no harmful influence on root development, whereas 2 and 4 p.p.m. of zinc inhibited growth very seriously.

VARIETAL REACTION TO ZINC

It was noted in this work that soybean varieties differed greatly in their toleration of an equal concentration of zinc in the nutrient solution. Of the four varieties being studied at this time, Mandarin, Mandell, Illini, and Boone, Mandarin showed the greatest tolerance and Boone the least.

To determine further the varietal reaction of soybeans to zinc, gravel boxes A and B were each planted to eight varieties of four plants each on April 18, 1938. For box A (Fig. 5) the pH of nutrient solution on April 22, 26, and May 2 was 6.0, 6.5, and 6.9 respectively. Box B (Fig. 6) remained at pH 7.0 throughout the test. The day temperature of the greenhouse ranged from about 70° to 85° F and the night temperature ranged from about 50° to 65° F.

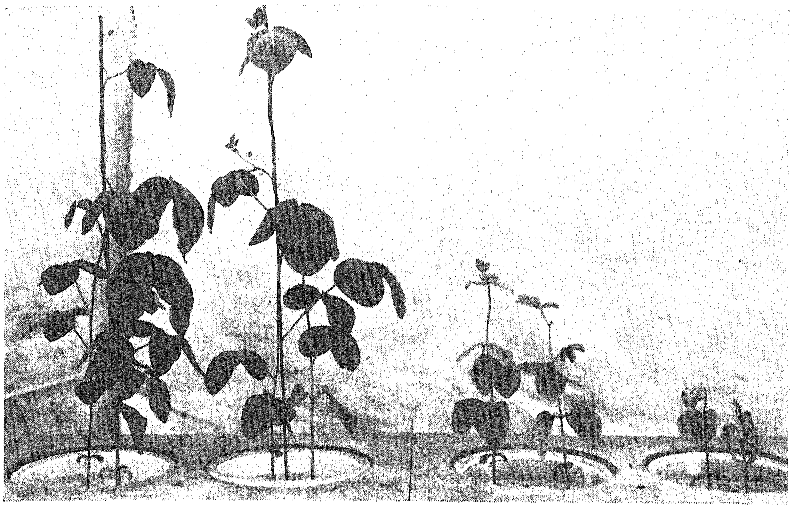

FIG. 2.—The effect of increasing the amount of zinc as zinc nitrate in the nutrient solution upon the growth of Hudson Manchu soybeans in crushed quartz. Planted October 20, 1938; photographed November 28, 1938.

The zinc concentration of these solutions was unknown; however, the results of later tests with Hudson Manchu and Peking indicated a concentration of about 0.3 p.p.m. and 2.3 mgms per plant.

FIG. 3.—The effect of increasing the amount of zinc as dissolved nutrient-solution-pump in the nutrient solution upon the growth of Hudson Manchu soybeans in crushed quartz. Planted October 20, 1938; photographed November 28, 1938.

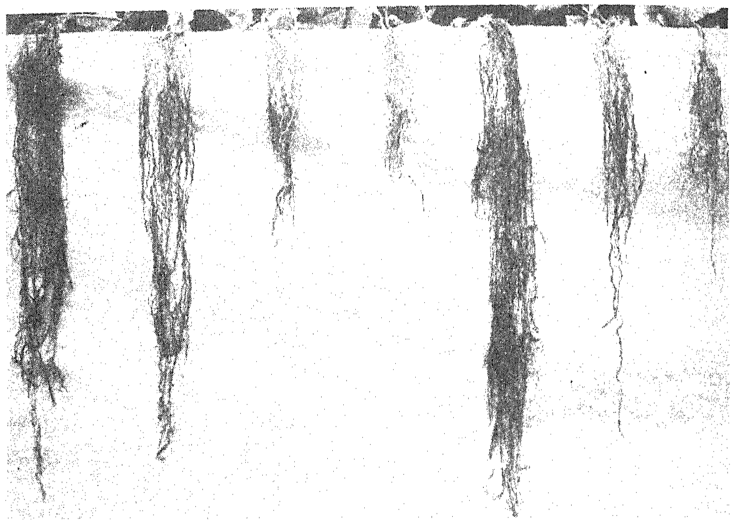

FIG. 4.—Effect of zinc on root growth of Hudson Manchu soybeans. Left to right: Check, 1 p.p.m., 2 p.p.m., and 4 p.p.m. of zinc as alloy pump, and 1 p.p.m., 2 p.p.m., and 4 p.p.m. of zinc as zinc nitrate. Planted October 20, 1938; photographed November 28, 1938.

The results of this experiment showed the order of the eight varieties in each box, based on increasing susceptibility to zinc, to be as follows:

Box A (Fig. 5)	Box B (Fig. 6)
Hudson Manchu*	Giant Green
Biloxi	
Mandarin	Mandarin
Habaro	Mandell
Harbinsoy	Mukden
Scioto	Virginia
Morse	Dunfield-B
Boone	Boone
	Peking

*The varieties in brackets appeared to give the same reaction.

In the front rows of box B (Fig. 6), Peking and Boone occur in adjacent rows and it may be observed that the former is more susceptible to zinc than the latter. It was also seen in boxes A and B (Figs. 5 and 6) that Hudson, Manchu, Biloxi, and Giant Green can successfully tolerate a higher concentration of zinc than Mandarin. So, among the additional varieties studied, Hudson Manchu was found to show a higher tolerance to zinc than Mandarin, and Peking to be more susceptible than Boone.

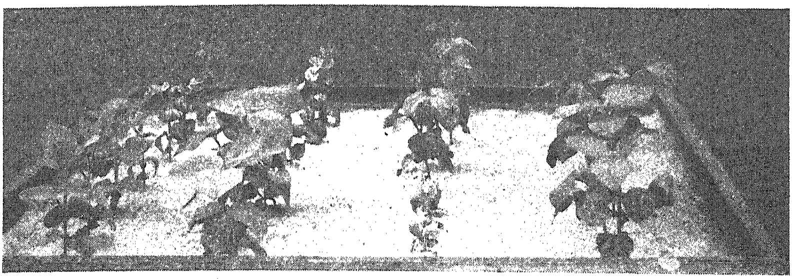

FIG. 5.—Box A, varietal reaction of soybeans to zinc in a nutrient solution with a slightly acid reaction. The varieties are, left to right back rows, Scioto, Morse, Mandarin, and Harbinsoy; front rows, Habaro, Hudson Manchu, Boone, and Biloxi. Planted April 18, 1938; photographed May 24, 1938.

These tests revealed that varieties of soybeans exhibit striking variations in reaction to a zinc concentration of approximately 0.3 p.p.m. in a slightly acid or neutral nutrient solution. The degree of damage from zinc may be said to increase with decreasing pH. Boone, growing in boxes A and B (Figs. 5 and 6), illustrates this point very nicely. In box A, with a slightly acid nutrient solution, this variety is severely damaged, while in box B, with a neutral nutrient solution, it shows only slight damage.

MAGNITUDE OF VARIETAL REACTION TO ZINC

The varietal difference between Hudson Manchu and Peking appears to represent the extremes in reaction to zinc, with the former

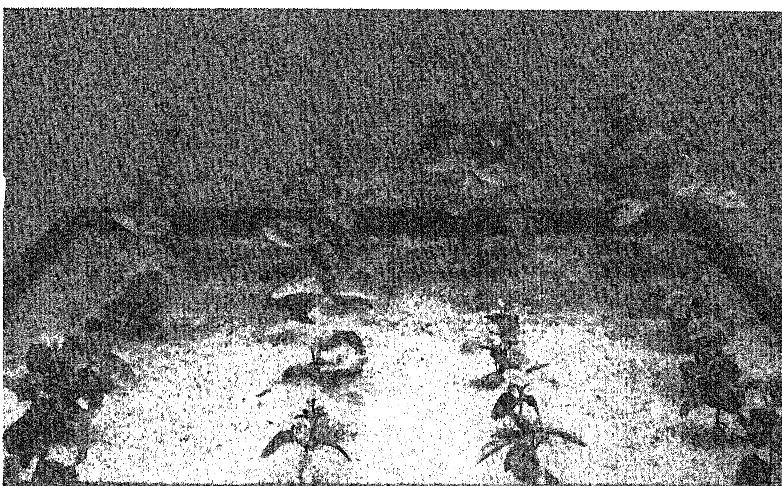

FIG. 6.—Box B, varietal reaction of soybeans to zinc in a nutrient solution with a pH of 7.0. The varieties are, left to right back rows, Virginia, Mandell, Giant Green, and Mandarin; front rows, Dunfield-B, Mukden, Peking, and Boone. Planted April 18, 1938; photographed May 24, 1938.

evidencing no deleterious effects from a concentration of zinc that killed the latter. These two varieties, therefore, were selected for the purpose of measuring quantitatively the difference in tolerance to zinc. An experiment was set up in which zinc nitrate was used as the source of this element.

Fourteen 2-gallon, glazed, earthenware jars filled with acid-washed crushed quartz and connected to seven pyrex bottles, each containing 18 liters of nutrient solution, constituted the apparatus. The composition of the nutrient solution used in the pot tests is given below;

Elements	N	P	K	Mg	Ca	S
Parts per million	140	62	234	97	200	192
Millimoles	10	2	6	4	5	6

Salts	Moles
KH_2PO_4	.002
KNO_3	.004
$Ca(NO_3)_2 \cdot 4H_2O$	.003
$CaSO_4 \cdot 2H_2O$	.002
$MgSO_4 \cdot 7H_2O$	.004

Also 0.5 p.p.m. of Mn as $MnCl_2 \cdot 4H_2O$, 0.2 p.p.m. of B as H_3BO_3 crystals, and iron as $FeCl_3 \cdot 6H_2O$ added to gravel when needed.

Each bottle was connected to two jars. In one of the two jars, two Hudson Manchu plants were grown and in the other jar two Peking plants. The concentration of zinc in the seven bottles was as follows: Bottle 1, check; bottle 2, 0.1 p.p.m.; bottle 3, 0.2 p.p.m.; bottle 4, 0.4 p.p.m.; bottle 5, 0.8 p.p.m.; bottle 6, 1.6 p.p.m., and bottle 7, 3.2 p.p.m. Bottles 1 to 7, therefore, contained no zinc, 1.8, 3.6, 7.2, 14.4, 28.8, and 57.6 mgms, respectively. Since each bottle received only the initial quantity of zinc during the experiment and since each supported four plants, the amount of zinc per plant for bottles 1 to 7 was none, 0.45, 0.9, 1.8, 3.6, 7.2, and 14.4 mgms, respectively. The experiment was started February 17, 1939, and the plants photographed May 19, 1939. Distilled water was used in making the nutrient solutions and in maintaining the volume during the course of the experiment. The solution was forced into the gravel by means of air pressure four times daily.

Under the conditions of this test it was found that Peking successfully tolerated a zinc concentration of 0.1 p.p.m. (0.45 mgms per plant) and Hudson Manchu successfully tolerated a zinc concentration of 0.8 p.p.m. (3.6 mgms per plant). It may be observed from Fig. 7 that Peking was damaged at 0.2 p.p.m. (0.9 mgms per plant) and completely destroyed at 0.4 p.p.m. of zinc (1.8 mgms per plant). Hudson Manchu (Fig. 8), on the other hand, while unaffected by 0.8 p.p.m. of zinc (3.6 mgms per plant) was killed by 1.6 p.p.m. (7.2 mgms per plant). It may be conjectured that about 1.2 p.p.m. of zinc (5.4 mgms per plant) is very close to the maximum concentration which Hudson Manchu can tolerate with little or no apparent ill effects. This statement is partially substantiated by the normal

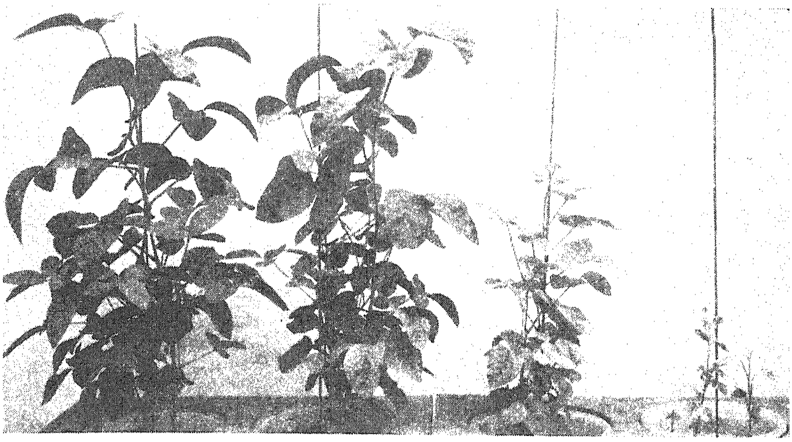

FIG. 7.—The effect of zinc as zinc nitrate upon the growth of Peking soybeans when produced in crushed quartz with nutrient solution. The zinc treatments, left to right, were: Check, 0.1 p.p.m., 0.2 p.p.m., and 0.4 p.p.m. Planted February 17, 1939; photographed May 19, 1939.

growth of Hudson Manchu at a concentration of 1 p.p.m. (4.5 mgms per plant) of zinc shown in Fig. 2.

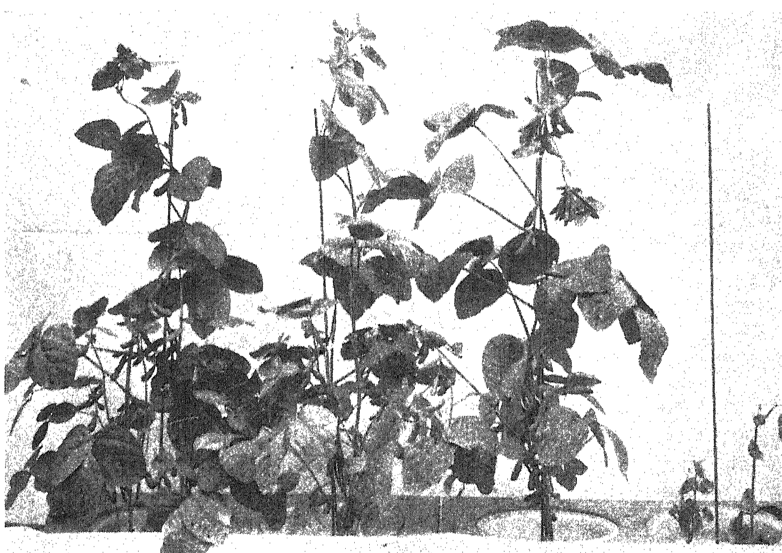

FIG. 8.—Effect of zinc as zinc nitrate upon the growth of Hudson Manchu when raised in crushed quartz with nutrient solution. The zinc treatments, from left to right, were: Check, 0.4 p.p.m., 0.8 p.p.m., and 1.6 p.p.m. Planted February 17, 1939; photographed May 19, 1939.

DISCUSSION

The reason why soybean varieties react differently to the same external concentration of zinc was not established in this work. However, since zinc is considered a direct toxicant, that is, requiring no oxidation-reduction reaction to convert it into a toxic form as is true of the chlorates, it may be assumed that varietal reaction is due either to differential absorption or differential tolerance, or to the interactivity of these two processes.

The apparent operation of the former of these two phenomena was observed by Hoener and De Turk (11) in their investigation of the nitrogen metabolism of Illinois high and low protein strains of corn. They state that, "The differential absorption of nitrates suggests the possibility of a 'resistance mechanism' to absorption. This resistance is lower in the high protein strain, being overcome by an external concentration of 100 p.p.m., of nitrate at which concentration abundant intake occurs. But in the low protein strain the resistance is much greater, being above 100 p.p.m., since it was only in the 200-p.p.m., culture that nitrate absorption occurred in more than minimal quantity."

The work of Yamasaki (21) also supports the view that there exists differential absorption among plant varieties for the chlorate ion. However, as stated elsewhere, he found that varietal distinction to $KClO_3$ was not due to differential absorption or tolerance but rather to differential ability of the varieties to reduce $KClO_3$ to hypochlorites. Apparently all varieties absorbed sufficient $KClO_3$ to cause their death had the salt been completely reduced to the toxic hypochlorite ion.

The functioning of "differential tolerance" of plant varieties to the same percentage concentration of elements within their tissue likewise has been noted. The work of Allen[6] shows that, whereas Virginia and Morse soybeans contained 2.9% potassium, respectively, when grown in nutrient solution containing 4 millimoles of potassium, the Morse tolerated this concentration more favorably than Virginia, as indicated by the dry weight data. These same varieties also when grown with 5 millimoles of phosphorus revealed that Morse tolerated this concentration to a more favorable extent than did Virginia. No chemical analysis of these plants were given; however, they were probably very similar at the time differential tolerance started to be manifested.

The soybean plants in this experiment were not analyzed for zinc because they were carried beyond the proper sampling period for final observation and photographing. Consequently, it is not known whether varietal distinction was effected by differential absorption or differential tolerance or by the interactivity of the two processes. However, the writer believed it worthwhile to illustrate these processes diagrammatically, on the basis of observed varietal reaction to zinc, for the purpose of clarifying the concept of each. Fig. 9 illustrates differential absorption and the interactivity of differential absorption and differential tolerance. The upper curve for Peking

[6] *Loc. cit.*

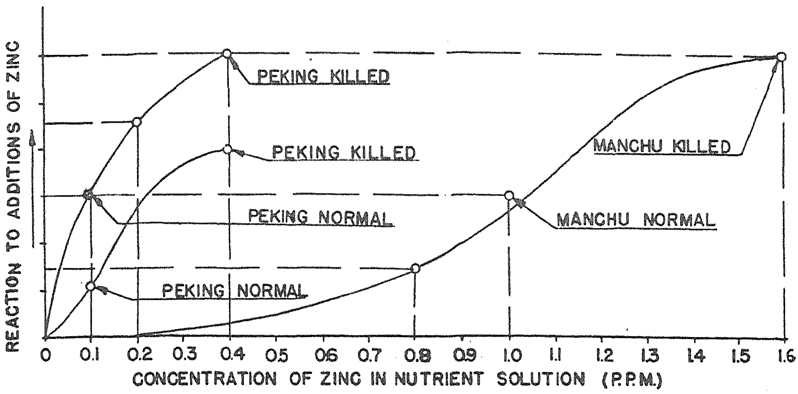

FIG. 9.—An illustration of differential absorption and the interactivity of differential absorption and differential tolerance of zinc by Peking and Hudson Manchu.

and the Manchu curve illustrate possible differential absorption since at 0.4 p.p.m. of zinc, for instance, Peking absorbed its lethal concentration of zinc whereas Manchu obviously did not. The lower Peking curve and the Manchu curve illustrate interactivity of the two processes in that both of these were operative in producing varietal distinction. For example, Peking not only possibly absorbed zinc at a faster rate than Manchu (differential absorption) but also was killed by a lower percentage concentration of zinc than Manchu (differential tolerance). Fig. 10 illustrates differential tolerance where both varieties possibly absorbed zinc at a correspondingly similar rate at each external concentration, until the resulting percentage of zinc in the tissue killed one variety (Peking) without apparent harm to the other variety (Manchu).

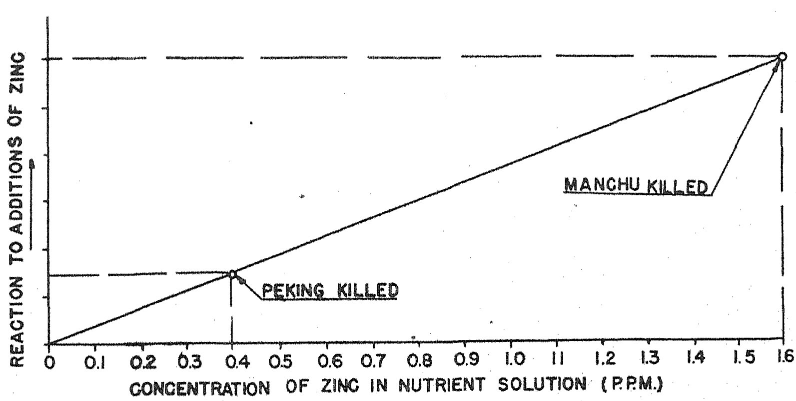

FIG. 10—An illustration of differential tolerance of zinc by Peking and Hudson Manchu.

CONCLUSIONS

The deleterious substance responsible for the death of the soybean plants attempted to be grown in the greenhouse during the fall of 1937 and spring of 1938 was zinc which had dissolved from the nutrient solution pump.

There exists a distinct varietal variation among soybeans in reaction to approximately 0.3 p.p.m. (2.3 mgms per plant) of zinc in a slightly acid nutrient solution when plants are grown in crushed quartz.

Hudson Manchu will successfully tolerate 8 and perhaps 12 times the external concentration of zinc as will Peking.

The mechanism of varietal reactions of soybeans to zinc was not determined, although differential absorption and tolerance are discussed in this connection.

The reaction of soybean varieties to zinc showed no correlation to percentage of oil or protein of the seed. Likewise, there appeared to be no consistant relationship between color of seed and plant reaction to zinc. Among the varieties studied, with the exception of Biloxi and Virginia, early maturity and resistance and late maturity and susceptibility appear to be associated. Also, with regard to size of seed and varietal reaction to zinc, it may be stated that the most resistant varieties were the largest seeded ones, while the most susceptible varieties were the smallest seeded ones.

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NOTES

THE USE OF THE NITROGEN ISOTOPE N^{15} IN DETERMINING NITROGEN RECOVERY FROM PLANT MATERIALS DECOMPOSING IN SOIL[1]

MANY practical agronomic problems center round the availability and recovery of the nitrogen of crop residues. The nitrogen transformations that occur when plant materials are incorporated in the soil are complex, though the general principles underlying them have probably been established. Studies in this field, however, will acquire a greater degree of precision and certainty when the nitrogen isotope of mass 15 is used as a tracer. This isotope can now be obtained in the form of ammonium nitrate, the ammonium ion of which is enriched very substantially above the normal figure of 0.38 atom %. Enriched nitrate can, however, be prepared by distilling off the ammonia and submitting it to biological oxidation in a percolating filter in which an active nitrifying population has been developed. If organic sources of nitrogen containing the isotope are desired they can be obtained by supplying an appropriate plant with an enriched ammonium or nitrate salt. With these three forms available it will be possible to examine in detail the nitrogen changes involved in the decomposition of plant materials. The chemical properties of the isotope are, of course, identical with those of the normal form, so that it appears in the tissues of plants and microorganisms in the same proportion as in the source of nitrogen supplied.

Accurate figures for the quantity of nitrogen immobolized by low-nitrogen residues will be obtainable by adding an enriched inorganic source and following the distribution of the isotope in the organic form at intervals. Likewise, the rate and amount of

[1]Journal paper No. J-1151 of the Iowa Agricultural Experiment Station, Project 789, Iowa State College, Ames, Iowa.

nitrogen liberated in the inorganic form from plant materials containing nitrogen in excess of that needed for microbial synthesis during decomposition in soil will be determinable accurately if the protein of the plant materials concerned contains a known amount of the isotope. Knowledge of the percentage of N^{15} in the nitrogen released from the plant material permits the calculation of the amount of nitrogen derived from that source, even though it is diluted by that concurrently becoming available from the soil organic matter, because the latter contains only the normal abundance.

In the course of some studies on the effect of inorganic nitrogen on the amount of nitrogen fixed by soybeans, which will be reported elsewhere, the opportunity was taken to test the procedure just described. Fifty-gram samples of ground soybean plants were incorporated in 12 kilos of soil-sand mixture in 2-gallon pots. The N content of the plant material was 2.15%, and the N^{15} present amounted to 0.684% of the N, or 0.304% in excess of normal. Soybean plants were grown on this mixture to near maturity (11 weeks, April 7 to June 24), and the tops and roots harvested for yield. Four replicate pots of inoculated and four of uninoculated beans were present in the experiment. After weighing, pairs of samples were combined for analysis. The relevant results are given in Table 1.

TABLE 1.—*Determination of N recovery from soybeans incorporated in a soil-sand mixture.*

Sample	Yield, grams	Mean	N content, %	N present, mg	N^{15} content, % of N	N^{15} present, mg	N^{15} from normal, mg	N^{15} excess, mg	N from soybean material, mg
				Uninoculated Soybeans					
A	45.4	47.0	1.94	912	0.474	4.323	3.465	0.858	282
B	48.5								
C	53.7	49.6	1.86	923	0.466	4.301	3.507	0.794	261
D	45.4								
				Inoculated Soybeans					
A	71.6	77.0	2.79	2,148	0.420	9.022	8.162	0.860	283
B	82.4								
C	65.8	66.5	2.87	1,909	0.430	8.209	7.254	0.955	314
D	67.2								

Because the N^{15} excess could only be derived from the nitrogen which became available from the plant material as it decomposed, it is possible to calculate the amount of the latter. This is the figure in the last column, which is obtained by dividing the amount of N^{15} excess in the plants by 0.304, the percentage excess in the soybean material incorporated in the soil. Although the nodulated soybean plants had an additional source of nitrogen, namely, that obtained by fixation from the air, the same calculation is applicable because atmospheric nitrogen also contains the normal abundance of N^{15}. It is possible that the uptake of nitrogen by the nodulated plants might be different to that by unnodulated plants; but the data here

are insufficient to answer this point. Taking the mean of all pots, it appears that 285 mg of N out of the 1,075 mg present in the soybean material incorporated became available and was taken up by the crop in 11 weeks, a recovery of 26.5%.

It will be noted that this answer is arrived at without the use of data from pots not receiving additions of the soybean material. In the past, reliance has had to be placed on differences in yield and nitrogen content between plants grown with and without the addition of the plant material in question, and the assumption made that the nitrogen derived from the soil organic matter is equal in both cases. This assumption is questionable and under some circumstances may be quite incorrect for two reasons, *viz.*, (1) if there is a great disparity between the root systems in the treated and untreated pots, the uptake of soil-derived nitrogen may be of a different order; and (2) the amount of nitrogen becoming available from the soil organic matter may be increased or decreased by the added plant material. These uncertainties are avoided by the use of the procedure suggested.

These data are presented, not because they have special intrinsic value, but as illustrative of the use of isotopic nitrogen as an aid in decomposition studies of this type.—A. G. NORMAN, *Soils Subsection*, and C. H. WERKMAN, *Bacteriology Section, Iowa Agricultural Experiment Station, Ames, Iowa.*

THE RAPID GERMINATION OF A SPECIES WITH A MUCILAGINOUS SEED COAT, *PLANTAGO FASTIGIATA* MORRIS

THE germination of the seed of *Plantago fastigiata*, a native winter annual, was investigated by Barton in 1936.[1] She obtained a germination of 27% at 20° C after storage for 9 months and suggested no other method of overcoming dormancy. The period after maturity in the spring is spent on the ground with germination occurring in the fall.

In 1941, a sample of this plantain, No. S-30,831, was received for test from Tucson, Ariz. The plantains are valued in the southwest where they furnish considerable winter and early spring grazing.

The seed had been harvested in April, 1941, and when tested in July after stratification in moist soil for 1 month, a method found beneficial for many lots of newly harvested seeds, this sample germinated 3.5% during a total incubation period of 4 months.

The mucilaginous layer surrounding the seed swelled considerably upon contact with water and appeared to be the probable cause of dormancy. Two simple methods of removing this layer were tried.

In September, 1941, 200 seeds were soaked 48 hours in water and then dried. The resulting coherent mass was broken up by hand pressure whereby much of the mucilaginous matter was reduced to flakes and removed from the surface of the seeds. A germination of 65.5% was obtained after 2 months' incubation on toweling in petri dishes at daily alternating temperatures of 15° to 32° C with light.

[1]BARTON, LELA V. Germination of desert seeds. Contr. Boyce Thompson Inst., 8:7–11. 1936.

21.5% dormant seeds still remained. Tests made simultaneously, without presoaking, on soil in petri dishes at the above daily temperature alternation, at 17° C, and at 10° C yielded 5.5%, 1.5% and 0% germination, respectively, within the 2 months.

These results were not entirely satisfactory because of the large amount of apparently sound ungerminated seed remaining, and a second method was therefore tried. Dry, finely divided peat was added to the soaked seed for the purpose of adsorbing the mucilage and the mass permitted to dry thoroughly before breaking it up. This treatment was suggested by a method used commercially in removing seeds of buckhorn plantain, *Plantago lanceolata* L., from red clover by means of moist sawdust.

In a test made in October, 1941, 200 seeds were soaked in water for 48 hours, then mixed with dry peat (Table 1). The mass, when thoroughly dry, was broken up as much as possible without injuring the seeds and the material incubated at 15° C for 17 hours and approximately 32° for 7 hours daily with light on soil in petri dishes. In 18 days 52.5% germination had occurred and in 28 days, 65%. When tests were transferred to a constant temperature of 17° C, 19% additional seedlings occurred, raising the figure to 84% over a total of 49 days. Although no unsoaked tests were made at this time, tests of 400 unsoaked seeds made in January, 1942, yielded only 19% seedlings at 17° C and 11% seedlings at 15° to 32° C daily alternation. There were indications from other incompleted tests that a much shorter period of soaking (3 hours) might be sufficient.

TABLE 1.—*Germination of the seed of Plantago fastigiata by removal of the mucilaginous outer layer of the seed coat.*

Date of test	Pre-treatment	Germination temperature, ° C	Germination %	Duration of test, days
		1941		
July 26	Stratified at 5°C, 1 month	15°–32°*	3.5	120
Sept. 10	None	17°	1.5	56
Sept. 10	None	10°	0.0	56
Sept. 13	None	15°–32°*	5.5	53
Sept. 13	Soaked 48 hours, then dried†	15–32°*	65.5	53
Oct. 27	Soaked 48 hours, then mixed with dry peat and dried†	15°–32°* then to 17°	65.0 84.0‡	28 49
		1942		
Jan. 14	None	17°	19.0	21
Jan. 14	None	15°–32°*	11.0	21

*15° C for 17 hours and approximately 32° C for 7 hours daily with light.
†The mass then broken up as nearly as possible to individual seeds.
‡81.5% in 31 days.

It is believed that soaking and thoroughly drying, with or without a dry material such as peat, and the subsequent removal of the

mucilaginous particles by mechanically breaking down the material as much as possible to the individual seeds before sowing, probably by means of a hammer mill, could be applied to the large-scale plantings of mucilaginous seeds such as those of the plantains.—M. P. MAULDIN, *Soil Conservation Service Seed Laboratory, San Antonio, Texas.*

FELLOWS ELECT FOR 1943*

THOMAS RAY STANTON

THE first Fellow to be presented to the Society was born in Grantsville, Md., September 23, 1885. He received his college training at the University of Maryland, graduating in 1910; and received his Master's degree in 1921. Since 1911 he has served with the U. S. Dept. of Agriculture and has been in charge of oat investigations since 1916.

In his service for the Department he has been instrumental in initiating, directing, and helping to correlate throughout the United States one of the most successful jobs of plant breeding in this or any other country, namely, the development of new rust, smut, and cold resistant oat varieties now coming into extensive use. The value of this work was indicated in several papers given at this meeting.

Without detracting from the credit due many able men who made important contributions to the program, it is proper to say that this man through his vision, perseverance, long service, and cooperative spirit has made a fine contribution to agronomy and to his country—THOMAS RAY STANTON.

FRANK LESLIE DULEY

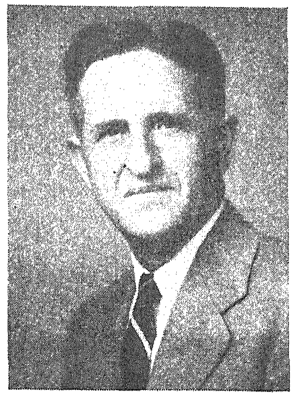
THE next Fellow is one of those thorough, careful, and painstaking scientists who have contributed so much to the development of improved agronomic practices.

DOCTOR FRANK LESLIE DULEY was born in Grant City, Mo., December 21, 1888, and received his Bachelor's and Master's degrees at the University of Missouri. During the next ten years he was on the staff of the Missouri Agricultural Experiment Station, advancing from an Assistant to an Associate Professor. In this period, while on leave of absence, he completed his graduate work at the University of Wisconsin, receiving his doctorate in 1923. From 1925 to 1933 he was Professor of Soils at Kansas State Agricultural College. Since 1933 he has served, with distinction, in the Soil Conservation Service.

Doctor Duley has worked in the field of soil fertility, plant nutrition, soil erosion control, and the conservation of soil moisture. He has served this Society and the Soil Science Society of America in many ways.

*Citations prepared by Dr. Frank W. Parker, Vice President of the Society.

HORACE JAMES HARPER



THE third Fellow to be presented to the Society is one of our most versatile agronomists and soil scientists. He was born in Vinton, Iowa, February 14, 1896, and received his Bachelor's and Master's degrees at Iowa State College. Following graduation he served on the Experiment Station staff.

In 1923 he completed his doctorate work at the University of Wisconsin, and it was there that I had the pleasure of coming to know this genial and enthusiastic scientist, who has made notable contributions in soil chemistry, soil fertility, and soil morphology before and since he went to Oklahoma in 1925.

This man has served this Society in many capacities. He was President of the Soil Science Society in 1942; is a member of the American Chemical Society and the International Society of Soil Science. He is appreciated by his associates—HORACE JAMES HARPER.

THOMAS BARKSDALE HUTCHESON

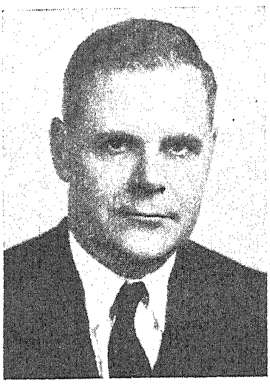
VIRGINIA is the "Mother of Presidents", but many Virginia farmers will tell you she has produced only one agronomist, PROFESSOR THOMAS BARKSDALE HUTCHESON.

Professor Hutcheson was born at Charlotte Court House, Va., in 1882. He graduated from the Virginia Polytechnic Institute in 1906 and received his Master's degree in 1908. With the exception of one year in Minnesota and another at Cornell, he has served Virginia continuously. Since 1914 he has been head of the Agronomy Department of Virginia Polytechnic Institute and Chief Agronomist of the Virginia Agricultural Experiment Station.

Professor Hutcheson is a farmer as well as an agronomist. He has operated a college farm of 2,000 acres for 20 years. With his brother he operates a 650-acre dairy farm and of course directs the work of the several substations of the Virginia Experiment Station. His versatility in the field of agronomy and agriculture is indicated by his monthly contributions to *Progressive Farmer* and frequent contributions to other farm papers. He is the most popular speaker before farm groups in Virginia and is a toastmaster *par excellence*. Professor Hutcheson is a great hunter and fancier, breeder, and trainer of dogs. Some of his dogs have won state honors in field trials.

Professor Hutcheson has been particularly active among southern agronomists, being a member of the Tobacco Research Committee and a regular attendant at the Association of Southern Agricultural Workers. He has been a member of this Society for many years and has served on many committees.

WILLIAM BECK KEMP



OUR next Fellow has had an unusual career in some respects. Like our first Fellow he is a native of Maryland and graduated from the University of Maryland in 1912. He then taught in a high school but soon went to West Virginia as Assistant Agronomist; returning after three years to Maryland as Extension Agronomist. His agronomic career was interrupted for a period of four years when he served as principal of a high school.

In 1921 he again became associated with the University of Maryland as Associate Agronomist, took his doctorate at American University in 1928, and has advanced to the head of the Department of Agronomy, and more recently has been Acting Director, of the Maryland Agricultural Experiment Station.

DOCTOR WILLIAM BECK KEMP'S scientific contributions have been in genetics, statistics, and more particularly in mathematical evaluation of biological data.

NORMAN JAMES VOLK

THE next Fellow to be presented this year has been a most fortunate individual, for like your Vice President he has had the privilege of working under both Emil Truog and Dean M. J. Funchess, as well as being closely associated with George Scarseth.

NORMAN JAMES VOLK was born in Oconto Falls, Wis., January 16, 1901. He graduated from the University of Wisconsin in 1923 and received his Master's degree the following year. After two years with the Texas Agricultural Experiment Station he became associated with the United Fruit Company from 1926 to 1936, but returned to Wisconsin for his Ph.D. in this period. Since 1936 he has been at the Alabama Agricultural Experiment Station and is now head of the Department of Agronomy.

Doctor Volk has worked on the nutrition and pathology of bananas, potash fixation, oxidation and reduction in soils, and in more recent years has given a great deal of attention to broad problems of soil fertility and fertilizer practices. Since his return from Central America he has been very active in the affairs of the Agronomy Society as well as the Soil Science Society.

MINUTES OF THE THIRTY-SIXTH ANNUAL MEETING OF THE AMERICAN SOCIETY OF AGRONOMY

THE Thirty-sixth Annual Meeting of the American Society of Agronomy was held in the Netherland Plaza, Cincinnati, Ohio, November 10, 11, and 12. There were 422 members and guests registered in attendance.

The general meeting of the Society was held Thursday morning, November 11, with President F. D. Keim presiding. Dr. Elvin Frolik, University of Nebraska, presented a paper on "Seed Production of Improved Strains of Grasses and Legumes." Dr. W. V. Lambert, Associate Director, Purdue University, presented a paper on "Streamlining Projects to Meet Current Problems." Both papers were well received and will be published in the JOURNAL.

The annual dinner was held jointly with the Soil Science Society of America on Thursday evening. Dr. F. D. Keim gave the Presidential address entitled, "Agronomy and Human Beings" (pages 995 to 1001 in this issue of the JOURNAL). Howard M. Call spoke on "The Old Home Farm—One Hundred and Forty Years Ago and Now." His address will be published in the 1943 PROCEEDINGS of the Soil Science Society.

Vice President Frank W. Parker announced the Fellows Elect for 1943 and presented certificates to the following: Horace J. Harper, Thomas B. Hutcheson, Frank L. Duley, William B. Kemp, Thomas R. Stanton, and Norman J. Volk.

The Crops Section held two general sessions and 12 sectional meetings. The Soil Science Society held two general sessions and 13 sectional meetings. Two joint sessions were held. A total of 178 papers were presented during the meetings.

The Society voted to approve an amendment to the by-laws covering membership options as follows:

The annual dues for each active member for the Society shall be as follows:

Option 1—Membership in the American Society of Agronomy and subscription to the JOURNAL	$5.00
Option 2—Membership in the Soil Science Society of America and subscription to the PROCEEDINGS	$5.00
Option 3—Membership in the American Society of Agronomy and Soil Science Society of America and subscription to the JOURNAL	$6.00
Option 4—Membership in the American Society of Agronomy and Soil Science Society of America and subscription to the PROCEEDINGS	$6.00
Option 5—Membership in the American Society of Agronomy and Soil Science Society of America and subscription to the JOURNAL and PROCEEDINGS	$9.00
Option 6—Membership in the American Society of Agronomy (for undergraduate and graduate students only)	$1.00
Option 7—Membership in the Soil Science Society of America (for undergraduate and graduate students only)	$1.00

A committee was approved to work in consultation with a committee from the Soil Science Society to secure greater cooperation with foreign scientists.

Reports by the Editor and Secretary-Treasurer and by the standing committees were presented and accepted and are appended hereto.

The Auditing Committee consisted of Dr. G. W. Conrey and Dr. A. T. Wiancko. The Nominating Committee consisted of President Keim, *Chairman*, Emil Truog, H. K. Hayes, M. A. McCall, and H. R. Smalley.

The Nominating Committee presented the name of H. D. Hughes for Vice President of the Society. Upon motion from the floor the Secretary was instructed to cast the ballot for the nominee and he was declared unanimously elected.

Respectfully submitted,
G. G. POHLMAN, *Secretary*.

REPORTS OF OFFICERS AND COMMITTEES

REPORT OF THE EDITOR

TAKING into account the complications of wartime with all their impact upon civilian activities and needs, we fared rather well in our publication requirements this past year. Just what 1944 holds for us, we shall not venture to predict. Sufficient unto the day are the rulings of the WPB, OPA, WMC, etc., etc.

Thus far, the JOURNAL has appeared very nearly on schedule and the reprints have been made available within a reasonable time. None of the printer's services are quite up to what we have been used to in the past, but due allowance must be made for the difficulties with which all private business must contend, especially with respect to shortage of labor and materials. I am satisfied that the printer will give the interests of the JOURNAL every consideration that circumstances permit.

Our most pressing immediate problem is that of paper. A ruling by the WPB on paper stocks for the last quarter of 1943, effective October 1st, made necessary a sharp revision in our publication schedule for the remainder of 1943 and means that Volume 35 will be at least 100 pages less than Volume 34. As a result the current volume will carry 107 articles as compared with 119 in 1942. In addition to the 107 articles, Volume 35 will contain 19 notes and 15 book reviews. Ten papers were deemed unsuitable or were withdrawn. As of October 25th, we have 22 papers on hand which have been approved for publication and 10 papers are in the hands of the Editorial Board. Of 20 papers returned to the authors for revision, several will doubtless be withdrawn or will be so completely revised as to constitute practically a new contribution upon their return. A total of 159 manuscripts had been received up to October 25th as compared with 169 for a similar period in 1942.

We are somewhat ahead of last year in the number of papers in reserve, including those approved for publication and those in the hands of reviewers or returned to the authors for revision. At this time the JOURNAL is made up through March 1944. Unless more stringent paper regulations are imposed, however, the publication schedule should not be further disrupted, and in fact, may improve slightly with time.

Since July 1st, we have been free of the censorship regulations which made it necessary that we obtain a special license from the Office of the Censor in order to mail the JOURNAL outside the United States and Canada. Even with this special license certain countries, including some South American countries, were closed to us. All of these limitations have now been removed, although we must, of course, observe the Code of Wartime Practices established by the Office of the Censor. These are commonsense regulations to prevent information of a vital nature reaching the enemy and have to do more with the reporting of the war news and of matters pertaining to war production, troop movements, etc., within this country than to the type of material that we publish in the JOURNAL.

Contrary to expectations, our advertising income has held up remarkably well through 1943, averaging well over a hundred dollars a month net. Early indications are that we shall be able to hold most of this through 1944.

The greatest satisfaction in the year's efforts, however, has been found in the fine relationships with contributors to the JOURNAL and with the Editorial Board. Naturally, there have been differences of opinion, but almost without exception the decisions of the Editorial Board have been accepted without demure. Once again we take pleasure in acknowledging the aid rendered by the Associate Editors in Crops and Soils and their corps of Consulting Editors. To these men alone belong the credit for maintaining the scientific standards of the JOURNAL which we cherish so highly.

The 1943 volume of the JOURNAL will complete 35 years of official publication by this Society. Your organization and your publications have withstood the impact of two world conflicts. In the midst of the greater one of these you hold a highly stragetic position on one of the most important of all the many "fronts" of this complex struggle—the mighty battle for food and more food for our armed forces, for our allies, for ourselves, and for the job of rehabilitation that will remain after the guns stop firing. Many of the answers to problems arising on the food production front are to be found in your JOURNAL, and upon many of you fall the responsibility of interpreting and putting into action the agronomic findings that help provide the food that is so sorely needed in such great abundance.

Much that we do may lack the glamor of gold braid and active military duty, but the times challenge our best efforts and the opportunities and responsibilities that are ours in helping meet a national crisis offer rich rewards in the satisfaction of having a vital place in the war effort. It is our earnest desire that the JOURNAL measure up in every respect to your expectations and to the needs of the times.

Respectfully submitted,

J. D. LUCKETT, *Editor*.

REPORT OF THE SECRETARY

THE membership changes in the Society during the past year are as follows:

Members, October 31, 1942		1,153
New members	148	
Reinstated members	7	
Dropped	83	
Resigned	11	
Deceased	5	
Net increase		56
Membership, October 29, 1943		1,209

The changes in subscriptions are as follows:

Subscriptions, October 31, 1942		493
New subscriptions	61	
Subscriptions reinstated	7	
Subscriptions dropped	42	
Net increase		26
Subscriptions, October 29, 1943		519

The paid up membership and subscription list by states and countries is as follows:

	Members	Subscribers
Alabama	22	1
Arizona	16	6
Arkansas	9	6
California	67	15
Colorado	17	1
Connecticut	12	4
Delaware	3	2
District of Columbia	72	48
Florida	27	5
Georgia	17	6
Idaho	7	2
Illinois	59	20
Indiana	34	5
Iowa	37	4
Kansas	40	3
Kentucky	12	5
Louisiana	22	8
Maine	3	1
Maryland	33	4
Massachusetts	9	6
Michigan	28	5
Minnesota	37	9
Mississippi	17	4
Missouri	20	6
Montana	8	6
Nebraska	37	3
Nevada	3	1
New Hampshire	2	1
New Jersey	20	6
New Mexico	10	4
New York	51	29
North Carolina	31	7
North Dakota	17	1
Ohio	41	9
Oklahoma	12	6
Oregon	17	4
Pennsylvania	27	9
Rhode Island	6	0
South Carolina	20	2
South Dakota	10	1
Tennessee	19	5
Texas	51	20
Utah	23	7
Vermont	4	1
Virginia	18	3
Washington	19	5

	Members	Subscribers
West Virginia	9	1
Wisconsin	43	7
Wyoming	7	1
Alaska	1	1
Hawaii	4	8
Puerto Rico	2	4
Africa	4	32
Argentina	11	17
Australia	0	27
Bolivia	0	1
Brazil	2	8
British Guiana	0	1
British West Indies	1	2
Canada	24	28
Ceylon	0	2
Chile	4	1
Colombia	2	3
Cuba	2	4
Egypt	0	1
El Salvador	2	0
England	1	13
Fiji	0	1
Guatemala	0	2
Haiti	1	0
Honduras	1	1
India	3	13
Ireland	0	1
Mauritius	0	1
Mesopotamia	0	1
Mexico	3	2
New Zealand	0	6
Nova Scotia	2	0
Palestine	0	1
Peru	3	3
Portugal	0	2
Scotland	3	1
Spain	0	2
Uruguay	1	0
U. S. S. R.	1	0
Venezuela	2	2
Wales	0	3
Total	1,205	510

The increase in membership is particularly gratifying. At present we have only four members who have not paid for 1943. Our total paid up membership

of 1,205 is the highest in our history. The increase in subscribers is small but does indicate continued interest in the JOURNAL wherever it can be secured.

The efforts of various members of the Society in helping to secure new members and to retain old ones is deeply appreciated. Your continued support will help to build our Society during this critical period.

Respectfully submitted,

G. G. POHLMAN, *Secretary.*

REPORT OF THE TREASURER

I BEG to submit herewith the report of the Treasurer for the year ending October 31, 1943.

RECEIPTS

American Society of Agronomy	$13,480.30
Soil Science Society of America	5,358.40
Marbut Memorial fund	524.71
International Society of Soil Science	55.00
Endowment fund, International Society of Soil Science	23.10
Total receipts	19,441.51
Balance on hand, October 31, 1942	3,619.26
Total income	$23,060.77

DISBURSEMENTS

American Society of Agronomy	13,550.60
Soil Science Society of America	5,966.91
Marbut Memorial fund	1,281.01
International Society of Soil Science	440.00
Total disbursements	$21,238.52
Balance	1,822.25
Checks outstanding	3.10
Balance in bank, October 29, 1943	1,825.35
Balance in savings bonds	2,520.00
Total assets, October 29, 1943	$ 4,345.25

These assets are divided as follows:

	Cash in bank	Savings bonds	Total
American Society of Agronomy	$ 746.77		$ 746.77
Soil Science Society of America (deficit)	−623.11		−623.11
Marbut Memorial fund	306.94		306.94
International Society of Soil Science	1,152.48		1,152.48
Endowment Fund, I.S.S.S.	242.27	$2,520.00	2,762.27
Total assets	$1,825.35	$2,520.00	$4,345.35

A breakdown of receipts and disbursements for the American Society of Agronomy for the year ending October 29, 1943 is as follows:

RECEIPTS

Convention receipts		$ 919.60
Miscellaneous receipts		52.32
Advertising		1,323.34
Reprints sold		1,767.83
JOURNALS sold		320.02
Subscriptions, 1942		368.15
Subscriptions, 1943 (old)		2,174.85
Subscriptions, 1943 (new)		292.40
Subscriptions, 1944 (advanced)		310.20
Dues, 1942		111.15
Dues, 1943 (old)		4.968.01
Dues, 1943 (new)		725.05
Dues, 1944 (advanced)		114.18
Index		6.00
Abstracts		.60
Total receipts		$13,453.70
Transfer from International Society of Soil Science		26.60
		$13,480.30
Balance in cash, October 31, 1942		813.97
Total income		$14,294.27

DISBURSEMENTS

Printing the JOURNAL, cuts, etc		$ 9,675.70
Salary of Editor		733.40
Postage, Editor and Secretary		211.51
Miscellaneous printing		194.20
Mailing clerk and stenographer		1,273.45
Refunds, checks returned, etc		18.05
Miscellaneous		231.39
Expenses for meetings		1,212.90
Total disbursements		$13,550.60
Total income	$14,294.27	
Less total disbursements	13,550.60	
Balance on hand, Oct. 29, 1943	743.67	
Checks outstanding	3.10	
Balance in bank, October 29, 1943		$746.77

The receipts are higher than last year, but expenditures were also higher, with the net result that we have $70.30 less in the treasury of the American Society of Agronomy than last year. Although this is not a large sum, it would seem wise to scrutinize carefully our expenditures and to look for means of increasing our income so that we can continue to show a favorable balance.

Respectfully submitted,

G. G. POHLMAN, *Tresaurer.*

AUDITING COMMITTEE

THE members of the Auditing Committee have examined the books of the Treasurer of the American Society of Agronomy and find the accounts correct as reported.

A. T. WIANCKO

G. W. CONREY, *Chairman*

FERTILIZERS

FERTILIZER GRADES

MEMBERS of the subcommittee in association with other agronomists and federal agencies have given much attention to the selection of a limited number of fertilizer grades to be sold in each state and particularly to the attainment of greater agreement between grades recommended in adjoining states. Consideration has also been given to procedures by which the number of grades to be sold in a given state after the war may be limited through mutual agreement between the industry, control officials, and agronomists. Agronomists in each state have been encouraged by members of the committee to collect from fertilizer companies the tonnages of different grades sold in the states each season. These data are entirely confidential and are compiled into a summary which is distributed to all companies submitting sales reports. This collection of sales data by agronomists has grown to be a regular procedure in a considerable number of states and constitutes a helpful contact between industry and agronomists.

C. E. MILLAR, *Chairman*

DIAGNOSIS OF NUTRIENT STATUS OF SOILS AND PLANTS

GOOD progress was made in stimulating interest among plant scientists in the diagnostic procedure. A number of papers were published during the year on various phases of this subject.

The effort of this committee in building a file or reference library of case histories is meeting with some success. A number of such cases will be published annually in the JOURNAL. It is suggested that those especially interested secure reprints from the authors. In all instances the authors of the case histories are to keep a supply of mimeographic copies available for distribution upon request. It is the hope of the committee that this file will serve as a handy reference on the subject.

The case histories collected to date have come entirely from members of the committee. This is not enough, therefore all scientists are invited to write up briefly, one page if possible, their experiences in diagnosing the nutrient status of soils and plants and send them to the Chairman, who will assemble all the cases for annual publication following the annual meeting of the Society.

GEORGE D. SCARSETH, *Chairman*

NITROGEN UTILIZATION

THE members of the Subcommittee on Nitrogen Utilization operated entirely by correspondence. Since every member of the Subcommittee was also a member of the National Joint Committee on Nitrogen Utilization, it was thought that we should function largely through the subcommittee of the National Joint Committee. During the course of the year, however, the Subcommittee did consider and act on one specific matter on which we wish to report.

Under date of June 2, the Subcommittee received from J. H. Stallings, Production Programs Branch, Food Production Administration, U. S. Dept. of Agriculture, Washington, D. C., three large sheets of data that had been compiled from publications of the several state agricultural experiment stations. These data showed:

1. Returns from pasture fertilization in terms of the composition of dry matter.
2. Returns from pasture fertilization in terms of digestible nutrients and of equivalent production of milk, beef, corn, wheat, oats, and cottonseed meal.
3. Returns from fertilization of hay crops in terms as shown in item 2.

These data were studied by the members of the Subcommittee with the result that on August 18 a letter was sent to Dr. Stallings asking him to extend his studies in an effort to translate the effects of fertilizers on haylands and past res into the following terms:

a. Pounds dry matter, protein, milk, and meat per pound N, P_2O_5, and K_2O.
b. Mineral content of plant produce as influenced by applications of N, P_2O_5, and K_2O.

A preliminary report on this was made by Dr. Stallings in early October. From this tentative report it was apparent that considerable further study would have to be undertaken to get a complete picture of our present knowledge on these matters, but progress is being made and, in due time, it should be possible to present some fairly dependable figures on the returns per pound of applied N in terms of the units mentioned.

It may be well to add, however, that experiments seldom give the best picture that could be presented for any given fertilizer element. Some limiting factor usually operates to prevent full effects from the element under study. We should be able to get larger and larger returns per pound of N in proportion as we know when, and when not, to use it. In other words, there are conditions under which its use can only result in negative effects. The problem is to eliminate such cases and study the use of N where the element has a real chance to do its work.

F. E. Bear, *Chairman*

FERTILIZER APPLICATION

THE Subcommittee on Fertilizer Application has continued to participate in the work of the National Joint Committee on Fertilizer Application. This has involved experiments in approximately 20 states on both field and vegetable crops. Comparisons have been made between the usual row or broadcast surface applications, and applications made by applying the fertilizer on the surface and plowing under, and by applying in bands at the bottom of the furrow; also various combinations of surface and plowing under. War conditions have necessitated some curtailment of the research program, but there has been an increase in the number of demonstrations relating to fertilizer application.

The work of this Subcommittee and the National Joint Committee on Fertilizer Application has undoubtedly materially contributed to the more effective use of fertilizers during the war period.

Robert M. Salter, *Chairman*

SOIL TILTH

THIS report is the product of this and all previous committees' activities. It discusses soil tilth, considers the need for tilth research, presents a broad research program, and states specific objectives for 1944.

DISCUSSION OF SOIL TILTH

It is difficult and perhaps impossible to define tilth in terms that will meet with general approval. This results from the broad usage of the term by farmers, teachers, engineers, and soil and plant scientists. A particular individual using the term tilth is influenced by certain interests and defines tilth in terms of his interests. Depending upon interests tilth signifies to different individuals the act of tilling, the tilled layer, the zone of roots, the physical condition of the soil

as it affects tillage, the physical condition of the soil as it affects plant growth, the feel of the soil, the physical condition of the soil, ease of handling, etc. Little can be gained by some particular group defining tilth in terms of their interests with the hope that others will use the term in the same sense. One way of avoiding difficulties is for each individual using the term in a publication to define tilth in the sense he intends to use it so that readers will not be mislead. Another possibility is to coin a new term that can be restricted to a particular usage of the now-too-general term, tilth.

This report concerns the physical condition of soil in its relation to life within the soil. Your committee has chosen the term "biophysical condition of soil" for this restricted meaning of tilth. Biophysical condition is not synonymous with physical condition. The physical condition of soil refers to a specific state of existence, and can be described entirely in physical terms. A given physical condition may represent many biophysical conditions depending upon the soil, organism and climate involved. While biophysical condition has a more restricted meaning than tilth it is still far too general to permit us to deal with the separate entities in the entire system or with their interrelations. For this reason we have selected the term "specific biophysical condition of soil" which denotes the physical condition of a given soil in its relation to a particular organism in a particular climate. The specific biophysical condition of soil may then be evaluated in terms of plant response. When we have learned how to characterize the physical condition of soil adequately we will probably be able to evaluate the specific biophysical condition in terms of soil qualities.

The soil characteristics that influence the biophysical condition are those that affect the air, water and temperature relations and possibly also the resistance to penetration. On a given soil, temperature relations and the resistance to penetration are largely governed by the air and water regime. It follows probably that an adequate description of the air and water interrelations in a soil would characterize the physical state of that soil as it affects plants.

The description of the air-water regime involves a knowledge of the amounts and distribution of both air and water in the soil. It also involves a knowledge of rates of movement. Thus a puddled surface soil or a compacted horizon assumes great importance.

It must be recognized that the biophysical condition is continually changing. Even in a soil in which the physical state does not change with time, the biophysical condition changes with changes in the amounts of air and water present. Where the physical state changes with time as is usually the case, the biophysical condition fluctuates markedly. The physical state is altered greatly by tillage, by the action of rain, by growing roots, and other biological activities, by wetting and drying, by freezing and thawing, and by chemical weathering.

In the remainder of this report tilth is used synonymously with biophysical condition.

THE NEED FOR TILTH RESEARCH

Approximately two-thirds of the total power consumption in farm draft work in the United States is expended in tillage. Over half this power is used in the basic operations of plowing and listing. One of the major objectives of tillage is to improve soil tilth. Cases can be cited where much of the money invested in tillage is wasted. Under other conditions, changes produced by soil manipulation effect such surprising increases in crop production as to suggest that an extension of the knowledge relative to the effects of tillage on soil and

subsequent crop growth might lead to a more economic system of soil management.

Tillage experiments in the past have compared implements or number of operations in their effects on yield. In none of these experiments has soil tilth been evaluated either before or after tillage. It is not surprising that results obtained by one investigator do not agree with those obtained by others. Nor is it surprising that a treatise such as "Plowman's Folly" has received so much publicity. The reason soil tilth has not been evaluated in tillage experiments is that methods are not available by which it can be determined. Neither do we know with any degree of certainty what soil tilth is required for our important crop plants.

No amount of empirical experimentation will tell us whether sub-surface tillage is superior to plowing, whether plowing is superior to disking, or what changes are desirable in the design of tillage machinery. Before we can make real progress we must know what soil physical state is desired for a given crop under specified climatic conditions. We must be able to measure the changes produced in soil tilth by our different management practices. A thorough fundamental study of soil tilth would seem to be of basic importance to agriculture.

A PROGRAM OF TILTH RESEARCH

Your committee believes research must answer quantitatively the following questions:

1. What are the soil tilth requirements of our important crops?
   - (a) Air requirements
   - (b) Water requirements
   - (c) Temperature requirements
   - (d) Resistance to root penetration

2. What is the soil tilth of a given soil before tillage?

3. How can soil in a given physical state be placed in state having desired tilth?
   - (a) Engineering aspects
   - (b) Soil aspects
   - (c) Cropping and microbiological aspects
   - (d) Environmental aspects

4. How stable is the soil tilth created by tillage?
   - (a) Effect of soil type
   - (b) Effect of previous cropping
   - (c) Effect of tillage
   - (d) Effect of climate and weather

5. Can guides be set up in terms of soil, crop and environment to serve as a basis for engineering processes to establish desired tilth?

ORGANIZATION OF TILTH RESEARCH

Soil tilth and tillage present problems of national importance. Only by joint action of federal and state agencies can we hope to obtain solutions to these problems.

In the above incomplete analysis of the tilth problem, it is evident that certain phases of the research must be carried out under closely controlled labora-

tory conditions (in deciding the tilth requirements of crops it will be necessary to control light, temperature, moisture, soil air, atmosphere, nutrients, and soil structure) while other phases of the research will require field plots under widely varying conditions. The Joint Committee has already recommended that a national laboratory be established to study soil tilth and it reiterates that recommendation now. The committee believes the tilth requirements of crops can best be ascertained at the national laboratory. All phases of the research would be cooperative between the national laboratory and the state stations. It would seem desirable to divide the country into regions where problems were similar. A group of collaborators from each region would then work with the national laboratory in formulating a program of research for that region. Undoubtedly there would be certain phases of the program that could be best investigated by the state experiment stations while other phases would require the controls existing at the national laboratory.

Our conception of the national tilth laboratory is that as it is an integral part of the Department of Agriculture, this program would not require the creation of any new agency or any reorganization within the Department. It would, however, require that funds be provided for the Bureau of Plant Industry, Soils, and Agricultural Engineering, to establish and operate additional facilities consisting of laboratories, greenhouses, various control apparatus, etc., for studying the plant physiological effects of various tillage practices and conditions of tilth and to supplement and work in connection with the machinery tillage laboratory. The activities of the laboratory would be decided cooperatively by the several states, the Soil Conservation Service, and the Bureau of Plant Industry, Soils, and Agricultural Engineering. We feel that tilth is a pressing problem of national concern and as such merits national attention.

OBJECTIVES FOR 1944

The committee realizes that very little new work on tilth will be possible until after the war. Also, granting that a program such as the one proposed is adopted, it will be some time before plant requirements can be evaluated. Because of this it would appear desirable to evaluate, insofar as possible, the changes produced in the physical state of soil by our present tillage implements. This knowledge is certain to be the basis of any future activities aimed at creating desired tilth.

Many experiment stations are now comparing plowing with sub-surface tillage. It may be that it would be possible to include disking also. These three methods constitute our present essentially different approaches to seedbed preparation. In one the residues are turned under, in another left on top of the ground, and in the third the residues are mixed in the surface soil.

The committee recommends that as many experiment stations as can do so, compare these three methods of tillage on one or more important crops. In addition to yields, as much information should be obtained as possible that will reflect on the air-water regime in the soils studied. In the event the physical studies cannot be made, it will be enlightening to have yields only.

The committee further recommends that it be authorized to submit this report to each of the directors of the several state experiment stations for their consideration. If a majority believe that a program along the lines suggested in this report is desirable, the report and the statements of the directors shall be submitted to the Administrator of Research of the Department of Agriculture

with the request that he approve the program and take such steps as are necessary to put the program into effect, as soon as conditions permit.

B. T. SHAW, *General Chairman*

For the American Society of Agronomy	For the American Society of Agricultural Engineers
L. D. BAVER	M. L. NICHOLS
E. N. FERGUS	J. H. NEAL
L. B. OLMSTEAD	A. P. YERKES
B. T. SHAW, *Chairman*	E. G. MCKIBBEN
	I. F. REED, *Chairman*

WAR AND POST-WAR ADJUSTMENTS

ONCE again the American Society of Agronomy meets with our nation still occupied with the conduct of a global war. We are now able to perceive shaping the military victory which is our immediate concern, but with the cessation of hostilities the United Nations will face an *even more prodigious* task in winning the peace. Unless we can win the peace we shall not have achieved true victory and we shall have an interlude which is but an armistice preceding an even greater holacaust. In building the "Temple of Peace", it is obvious to all thinking people that an attempt to provide adequate food for the peoples of the whole world will be a most enduring foundation stone. So huge a task cannot be the responsibility of any one country, but of all countries working in cooperation.

In the early summer of 1943 we were able, for the first time in the history of the world, to witness the co-operative planning of the strategy of peace, for at Hot Springs, Virginia, the government of the Unites States was host to the United Nations Conference on Food and Agriculture. The prime purpose of this conference, which brought together representatives of 44 nations, was to consider the world problem of food production and distribution after the war. The report of the conference shows that the delegates devoted most of their discussions to the problem of providing more and better food for 2,000 million people. The majority of the proposals for expansion of agricultural production, the improvement of nutrition and the increase of consumption are specifically directed to this end. It is a tragic fact that three-quarters of the 1,150 million inhabitants of Asia are living below decent and minimum health standards, that malnutrition exists among large segments of the peoples of Europe, Africa, various colonial territories, South and Central America, and to a lesser extent, in our own land.

It has been estimated that to "ensure all sections of the population. . . have enough of the right kinds of food. . . on a world basis would require expansion of production of the following orders of magnitude: cereals, 50%; meat, 90%; milk and other dairy products, 125%; vegetable oils, 125%; and fruits and vegetables, 300%."

Food policy and agricultural policy are inseparably intertwined, and raising the standard of nutrition among the nations must have profound effects on the domestic policy of every agricultural country. It seems apparent, that to provide these higher standards even only for our own people, would entail a greatly increased output of food. While such considerations are largely the responsibility of government, agronomists must inevitably serve a most significant function in carrying governmental policy into effect.

Conscious of our past successes, yet we must be vitally aware of our future responsibilities in helping to solve the tremendous problems and in making the large adjustments that will be necessary. Last year at this time, a committee of the American Society of Agronomy clearly enunciated certain recommendations which are as urgent now, as then (this JOURNAL, Volume 34, pages 1150–1152). At this juncture, the present committee established to consider War and Post-War adjustments reiterates those and emphasizes their urgency. At the same time it commends to the Society as a whole, as well as to its individual members, the following considerations:

1. Those nations which emerge from the present conflict with their programs of basic research most nearly intact will have the best opportunity of winning the peace. It behooves agronomists, as public servants, to maintain and strengthen standards of professional attainment and practice.
2. We must be able to discern and understand the needs of the times with clarity of vision and purpose so that, in proper perspective, we can correlate our energies and programs of endeavor into an integrated panorama of research, teaching and extension.
3. As agronomists, we shall achieve the greatest good in the shortest time, if we will expand our co-operative efforts, between workers within and between institutions, as well as between our colleagues in other nations. It is probable that there will be many calls from other countries for United States' agronomists to assist these in establishing their own agriculture on a firmer foundation. The loan of well trained agronomists to foreign governments would be one of the most effective aids we could render.
4. Despite the remarkable accomplishments of the past, there are undoubtedly directions in which further improvements can be accomplished in eliminating the less profitable endeavors in agronomic research, extension, and teaching, and in directing greater emphasis to problems of the most vital import to agriculture.
5. We must continue to strengthen and develop programs of plant breeding so that farmers will be able to grow crops that can better withstand the ravages and hazards of diseases, of insects and of weather. Similarly in the field of plant nutrition we must evolve more effective methods.
6. While agronomic extension is accomplishing results of first rate significance, it is essential that we achieve a still higher degree of effectiveness.
7. With the cessation of conflict and the consequent demobilization of the armed services, we must take up with renewed vigor and enterprise the teaching and training programs that have of necessity i een temporarily reduced or entirely eliminated. Experience following World War I suggests that teaching institutions will again have a greater influx of students than at any previous time in their history. Departments of Agronomy will most assuredly face tremendous problems concerning adequate teaching personnel, laboratory and class room facilities and quality of instruction. It appears that our government will correctly emphasize education opportunity for our returning servicemen. They will return to our institutions with a large and varied experience of the world in general, and they shall have the right to expect that we as teachers will make our instruction of the most challenging order. They will not be satisfied with pedantic, dull and uninspired instruction, nor will they be in a mood to accept it. A substantial increase in teaching personnel will most certainly be required.

Furthermore, it has been estimated that there may be approximately 1,000,000 servicemen who may be partially disabled, and for whom it will be necessary to devise special courses of instruction and training in order to enable them to be engaged in a productive capacity. It is possible that one-half of these will require courses of college level.

8. The future demands of agronomic research, teaching, and extension will require that we recruit as soon as possible the most promising candidates for instruction and training in these respective fields so that in the greatest degree we can recoup the lost ground occasioned by the war. We must assure these men a sound basic professional training, as well as a good general education that will enable them to undertake their tasks with vision and in true perspective.

9. It is to be expected that after this war, we shall be called upon to help in training the young men of other nations, especially those of Central and South America and China. They will probably come to us in considerable numbers and with varying degrees of accomplishment. As agronomists we shall share in this responsibility and service, and we must be prepared to devote the necessary energy and tact in preparing them adequately for the service of their own peoples.

10. It is urged that agronomic institutions give immediate and urgent consideration to the problem of assuring and safeguarding adequate supplies of foundation seed for the best varieties of important farm crops. As agronomists we carry heavy responsibilities in this respect. This is especially true of adapted corn hybrids, disease resistant varieties of cereals, and superior strains of legumes and grasses. In the past season our own country has faced severe seed shortages of many important crops. An abundant seed supply is as necessary as a sufficiency of munitions. We need it now, both for our own requirements and for all the United Nations, who now of dire necessity must largely depend on the North American continent for meeting present and future seed needs in restoring to productivity the lands ravaged by war.

11. It is recommended that the American Society of Agronomy use the utmost influence in urging the appropriate federal authorities to make more liberal assignments for the manufacture of critically important farm machinery. With the extreme shortage of farm labor now existing and with the very rapid deterioration of existing machinery, this need is vital to the immediate war and post-war periods in maintaining present levels of production for the expanded production that is required.

12. Similarly the Society urges that more adequate consideration be given to the fertilizer requirements of crops vital to the national effort.

13. Since the soil, our greatest material asset, is being depleted even more rapidly than before the war, it is urged that agronomists meet this challenge by stimulating and organizing the general adoption of those practices which both conserve and restore soil productivity.

14. It is recommended that the American Society of Agronomy appoint a committee to survey the possibilities of establishing suitable courses of instruction and training for the servicemen demobilized from the armed forces, and that this committee report to the next annual meeting of the Society.

15. Finally the American Society of Agronomy, as an organization of scientifically trained men fully cognizant of their responsibilities toward the nation's

crops program, again pledges itself to give every possible aid and counsel to the government in the national purpose in prosecuting the war and in meeting the challenge of peace.

M. F. MILLER
N. P. NEAL
R. D. LEWIS, *Chairman*

EXTENSION PARTICIPATION

AT A conference during the American Society of Agronomy meetings at St. Louis in November, 1942, the extension agronomists favored presenting a request for a special session for extension agronomists at the 1943 meeting. This request was granted. Correspondence with chairmen of departments and extension agronomists throughout the country indicated that for the 1943 session at Cincinnati, a majority favored the presentation of extension methods rather than research material. This expression of opinion guided the Committee in formulating the program presented at the 1943 meeting.

At the conclusion of the 1943 session, a motion was adopted requesting the Committee to appoint a Subcommittee to work with Dr. L. F. Graber in the preparation of a paper for publication in the JOURNAL, summarizing the discussion lead by Dr. Graber, dealing with the subject "Should Extension Agronomists be Employed in Part-time Research?" The Subcommittee appointed includes Dr. E. L. Worthen of New York; Dr. C. F. Simmons of Arkansas; and Dr. W. H. Pierre of Iowa.

At the same time it was agreed that the subject, "Integration of Research and Extension" should be presented at a general session of the 1944 meeting of the Society. It was agreed that although there be separate extension sessions at subsequent meetings, subjects such as the following, of interest to both research and extension men, be included in the general research program: (1) Presentation of research material by a research worker, followed by a report of the activation of this material by an extension worker; (2) summarization of research material dealing with subjects of special interest.

O. S. FISHER
IDE P. TROTTER
L. E. WILLOUGHBY
EARL JONES
D. L. GROSS, *Chairman*

BIBLIOGRAPHY OF FIELD EXPERIMENTS

THE committee has compiled a bibliography of 124 titles of the more important contributions on the methodology of and interpretation of results of field, pasture, and range experiments, either reported since or not included in the revised bibliography published in this JOURNAL (Vol. 25: 811–828, 1933; and the additions in Vol. 27: 1013–1018, 1935; Vol. 28: 1028–1031, 1936; Vol. 29: 1042–1045, 1937; Vol. 30: 1054–1056, 1938; Vol. 31: 1049–1052, 1939; Vol. 32: 984–986, 1940; Vol. 33: 1124–1127, 1941).

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F. R. IMMER
H. M. TYSDAL
H. M. STEECE, *Chairman*

VARIETAL STANDARDIZATION AND REGISTRATION

THE following crop varieties have been submitted to the committee during the year, and have been approved for registration:

BARLEY

Glacier, developed by the Montana Agricultural Experiment Station and the U. S. Dept. of Agriculture.

FLAX

Crystal, developed by the Minnesota Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Royal, developed by Dr. J. B. Harrington at the University of Saskatchewan.

OATS

Cedar, developed by the Iowa and Nebraska Agricultural Experiment Stations and the U. S. Dept. of Agriculture.

SORGHUM

Westland, developed by the Kansas Agricultural Experiment Station.

SOYBEANS

Patoka, developed by the Purdue University Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Gibson, developed by the Purdue University Agricultural Experiment Station, and the U. S. Dept. of Agriculture.

Earlyana, developed by the Purdue University Agricultural Experiment Station and the U. S. Dept. of Agriculture.

WHEAT

Fairfield, developed by the Purdue University Agricultural Experiment Station.

Carleton, developed by the North Dakota Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Stewart, developed by the North Dakota Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Newthatch, developed by the Minnesota Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Descriptions of these new varieties will be published in the JOURNAL.

In accordance with the authorization approved by the Crops Section of the Society at the 1942 annual meeting, the committee is considering final plans for the registration of improved varieties of various grasses.

During the year, the committee also approved a general plan for the registration of improved varieties developed by private plant breeders. Under this plan, the agricultural experiment station of the state in which the private breeder is resident will be requested to assume responsibility for conducting the necessary tests and for officially sponsoring the request for registration. In view of the fact that a number of varieties of various crops developed by private plant breeders have proved outstandingly valuable and are now on the list of recommended varieties in various states, this seems to be a desirable move. The committee believes that the Society should recognize valuable germ plasm and meritorious accomplishment from whatever source it may come.

A. C. ARNY — L. F. GRABER — W. J. MORSE
H. B. BROWN — H. K. HAYES — T. R. STANTON
J. A. CLARK — E. A. HOLLOWELL — T. M. STEVENSON
E. F. GAINES — R. E. KARPER — G. H. STRINGFIELD
M. A. MCCALL, *Chairman*

NOMENCLATURE OF GENETIC FACTORS IN WHEAT

THE committee has continued work throughout the year. A proposed set of symbols and system of nomenclature has been agreed upon. The symbol consists of the initial letter of the name of the character or of the initial letter of some other appropriate word in the name. Numerical subscripts will designate different gene symbols for a character. This system is flexible and can be expanded easily. Only characters which have been studied sufficiently to determine their inheritance will be given subscripts.

Some of the committee members have been unable to submit detailed reports on the characters assigned to them due to the war. However, it is hoped to receive these reports in the near future so that a complete report can be submitted to the society.

It is recommended that the present committee be continued another year.

FRED N. BRIGGS — J. B. HARRINGTON
L. P. REITZ — E. R. AUSEMUS, *Chairman*
W. W. WORZELLA

METHODS OF SEED PRODUCTION AND UTILIZATION OF IMPROVED STRAINS OF FORAGE CROPS

AT THE Washington meeting in 1941 the Extension Committee of the Society recommended the appointment of, "A standing committee composed of research and extension men from important seed producing and seed using areas to correlate the production and utilization of improved strains of forage crops". Literally interpreted, this committee might result in conflicts with the work of several other organizations and groups. So this committee regards its prime function is to call the attention of all agronomists to:

1. Developments in superior strains of forage crops having probable regional significance.
2. Significant interstate programs for the production and utilization of improved strains of forage crops.
3. Situations and processes requiring solutions and actions to aid in gaining effective production, utilization, and preservation of improved strains of forage crops having regional significance.

First, we commend the officers of the Crops Section of the Society for the many contributions at this Cincinnati meeting to methods of breeding forage crops and to the problems of seed production and seed processing.

Experience has shown, however, that much good germplasm has remained unutilized as a result of unsolved problems in producing and distributing the seed, or as a result of lack of planning for seed production, or because of inadequate knowledge and appreciation by agronomists as well as by farmers of the values of improved strains or composites having regional (interstate) significance.

We believe it fundamental that, with the advent of more and more improved strains for forage crops, agronomists, seed producers, seedsmen, and farmers must fully appreciate that the production of seed of the affected crops will be shifted from incidental, "side-line", or "commodity" enterprises to deliberate planned programs of production and distribution.

At this time, the committee calls the attention of agronomists to the following relatively new improved strains and composites which have regional significance and whose performance probably justifies greater efforts in seed production and extension of use in those states to which they are specifically adapted:

Cumberland red clover (Reg. No. 1).[1]
Midland red clover (Reg. No. 2).[1]
Evergreen biennial white sweet clover (Reg. No. 3).[2]
Spanish biennial white sweet clover (Reg. No. 1).[2]
Madrid biennial yellow sweet clover (Reg. No. 2).[2]
Ranger, Buffalo, and Atlantic alfalfas
Achenbach, Fisher, and Lincoln strains of brome grass
Marietta, Lorain, and Cornell 1777 timothys
Tift sudan grass

This list is probably not complete and the committee would appreciate information of other strains or composites having regional significance and for which interstate programs of seed production and utilization have been developed.

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[1]HOLLOWELL, E. A. Registration of varieties and strains of red clover, I. Jour. Amer. Soc. Agron., 35:830–833. 1943.

[2]HOLLOWELL, E. A. Registration of varieties and strains of sweet clover, I. Jour. Amer. Soc. Agron., 35:825–829. 1943.

With the exception of Atlantic alfalfa and Tift sudan grass, seeds of the above-listed strains and composites were in May-June of 1943 declared eligible for loans at premium rates by the Commodity Credit Corporation.

Interstate programs for the production of seed of improved strains have been developed through the International Crop Improvement Association in cooperation with the states originating the strains, seed producing states, and the Division of Forage Crops of the U. S. Dept. of Agriculture. Midland and Cumberland red clovers, and Ranger alfalfa are gaining rapidly in importance as a result of programs of this type. The Alfalfa Improvement Conference worked closely with the International Crop Improvement Association in developing the seed production program with Ranger.

The significance of seed certification as an aid to stimulating and guiding the increase of seed of improved strains has this year been effectively developed in the general meeting by E. F. Frolik. The International Crop Improvement Association is now in the midst of conducting an extensive analysis of the standards and procedures used in various states in the growing, processing, inspecting, and certifying of improved strains. Greater uniformity of concepts and procedures as between states should logically result, as will also higher standards and a more general realization of the fact that proved superior heredity is the true basis of seed certification.

To the committee have come many instances where plant breeders and seed production agronomists are "floundering around" or seeking information on systems of protecting and increasing superior germplasm of new strains of forage crops, and specifically concerning the policies and methods involved in initiating seed certification systems. As there are many aids to be found in the published proceedings and reports of the International Crop Improvement Association, this committee recommends that forage crop breeders and seed production agronomists acquaint themselves with typical state and interstate programs that have been and are being developed through the International Crop Improvement Association.

O. S. Aamodt	L. F. Graber	H. C. Rather
H. R. Albrecht	F. V. Grau	H. A. Schoth
A. L. Clapp	J. C. Hackleman	H. M. Tysdal
O. S. Fisher	E. A. Hollowell	R. G. Wiggans
E. F. Frolik	R. D. Mercer	R. D. Lewis, *Chairman*

CROP TERMINOLOGY

THIS committee was organized a year ago at the suggestion of the Committee on Terminology of the Soil Science Society of America, which had had several strictly crop terms referred to it for definition.

Uniform usage of technical terms is important, but it cannot be obtained without someone's giving up the use of terms to which he has become accustomed. Before making this necessary, every effort should be made to choose the *best* term, all things considered, including present usage.

The committee does not feel that there is time at the annual meeting to discuss these terms. In order to avoid arbitrary action, the committee is submitting its recommendations on these terms at this meeting and suggesting that they be formally acted upon, after opportunity for amendment, at the next annual meeting. The committee requests that those who have objections to any of these

recommendations write them to any member of the committee. Terms so far submitted to the committee are as follows:

Ensilage, silage, ensile, and silo

C. V. Piper wrote in 1924: "Silage was originally called *ensilage*. . . The verb form *to ensile* is now preferred". Since this has been the most general usage for at least 30 years, the Committee recommends that we use *silage* rather than ensilage for the noun, and *ensile, ensiling, ensiled* as the verb forms.

Grass silage, hay crop silage, meadow crop silage, grass, and legume silage

All of these terms have been used in this country to designate silage made from these grasses, legumes, or mixtures of them which have heretofore been harvested for hay or pasture. The difficulty, of course, arises from the fact that we have no accepted short general term to designate "grasses, legumes, or mixtures of them". *Grass silage* is almost universally used as a general term in other English-speaking countries. In the opinion of the committee, the other circumlocutions are too long ever to win general acceptance, even among agronomists, to say nothing of the public. Consequently we recommend that *grass silage* be used as the general term, and that *alfalfa silage, clover silage, alfalfa-timothy silage,* and similar definite expressions be used where possible.

Grass seed, forage grass seed, forage crop seeds, etc.

This set of terms is merely another example of our lack of an accurate general term to include grasses and legumes taken together or separately. Farm usage will probably continue to refer to all small seeds as grass seed. For more precise distinction the committee recommends the use of the term *forage crop seeds.*

Sward, turf, sod

These terms are nearly synonymous. All refer to a more or less dense growth of grasses and other similar crops. *Sward* is nearly obsolete and fills no necessary place in technical literature. Insofar as it has any different meaning from the others it is used somewhat more with reference to the *surface,* only, of a lawn, playing field, or other grass growth. *Turf* definitely refers to the matted stratum of earth filled with grass roots, as well as the surface. *Turf* is used in England as *sod* is in this country, for a thin layer of grass-filled earth used to establish grass on a new surface.

These words all connote grass, and there is no word in English which specifically designates a layer of earth filled with roots other than those of grass. Recently, there has been a definite tendency for agronomists to expand the use of sod to include this meaning: e.g., an alfalfa *sod,* a clover *sod.* The committee recommends that this extension of the use of *sod* be encouraged, reserving *turf* for sods composed largely or entirely of members of the grass family.

Birdsfoot trefoil

In accordance with rules adopted by "Standardized Plant Names", the committee recommends that this name be written in the form above—no apostrophe, and a compound word rather than a hyphenated word or two words for "birdsfoot".

Reed canarygrass

This name is frequently written Reed's canary grass. This name was not derived from a man's name, but from the resemblance of the grass to reeds, so

reed should not be capitalized. The committee follows "Standardized Plant Names" in recommending the compound form *canarygrass*.

Nurse crop, companion crop

Nurse crop is the older, better known term for small grains in which forage crops are sown. It has been used for so long that many persons thought they really were helpful and protective instead of serious and often destructive competitors. Agronomists at the Ohio Agricultural Experiment Station working on seeding problems, looked for a term which more accurately expressed the real relationship between the crops, and in Bulletin 588 of that Station and some earlier mimeographed publications introduced the term *companion crops*. This term is open to several objections, but no better one has been suggested, and the term has been used by many others since the publication of Bulletin 588. The committee recommends that *companion crops* rather than "nurse crops" be used to designate those crops in which other crops are sown. The term may be used to refer to corn, soybeans, and other crops which have never been called "nurse crops".

Meadow

In modern agronomic usage, *meadow* always refers to a field in which biennial or perennial crops are grown for hay, and the Committee recommends such use of the word. Historically, the word has been used for any grassland, with the connotation of low-lying land.

K. S. QUISENBERRY
C. P. WILCIE
C. J. WILLARD, *Chairman*

(N. B. At the request of Dr. C. J. Willard this report was approved provisionally so as to be subject to amendment, revision and formal action at the next meeting of the Society.)

STUDENT SECTIONS

IN NEARLY every instance, the Student Agronomy Clubs are inactive, and will no doubt remain so until after the war. Since the last meeting, approximately 400 membership certificates have been issued, which indicates the interest students had in these groups. With the continued support of the Society, the Clubs may be expected to again become active following the war.

As was announced previously, no student essay contest was held this year.

R. L. CUSHING
G. H. DUNGAN
J. B. PETERSON
M. B. STURGIS
H. K. WILSON, *Chairman*

MONOGRAPHS

ALTHOUGH discussions of methods of financing monographs and of suitable subjects are continuing, no definite plans have been developed. The Committee invites suggestions from the members of the Society as to appropriate subjects and prospective authors.

CHARLES E. KELLOGG, *Chairman*

RESOLUTIONS

YOUR Committee on Resolutions most respectfully calls to the attention of all members of the American Society of Agronomy, the names of seven of our number who have been taken from us since we last met, as follows:

H. L. Westover, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C., died January 2, 1943.

W. A. Leukel, University of Florida, Gainesville, Fla., died April 27, 1943.

W. B. Ellett, Agricultural Experiment Station, Virginia Polytechnic Institute, Blacksburg, Va., died May 12, 1943.

G. R. Hyslop, Head of Department of Farm Crops, Oregon State College, Corvallis, Ore., died July 24, 1943.

Alfred Smith, Associate Professor of Soil Technology, University of California, Davis, Calif., died August 24, 1943.

G. M. McClure, Assistant Professor of Agronomy, Ohio State University, Columbus, Ohio, died September 24, 1943.

Fred H. Bateman, A. B. Farquhar Company, Ltd., Greenloch, N. J., died October 13, 1943.

Appended to this report are statements summarizing the life and professional work of our departed members which include the sincere expression of sorrow and loss on the part of the American Society of Agronomy. Our sympathy goes out to their respective families, the institutions they served, and their former associates. Copies of these resolutions as published in the JOURNAL will be sent to the bereaved families.

TO OUR MEMBERS IN SERVICE

The American Society of Agronomy at its annual meeting in Cincinnati, Ohio, November 10–12, 1943, has keenly missed the presence and the contributions of many of its faithful members who are now in the Armed Services.

To all of these wherever they may be, we send our sincere and cordial greetings. We congratulate each of you on your great and unselfish contribution to our nation's welfare and perpetuation.

May you soon return to us with a wealth of new experiences and observations which will be of value to you and to us in the productive years which lie ahead.

R. I. THROCKMORTON J. D. LUCKETT, *Ex-officio*
R. W. CUMMINGS IDE P. TROTTER, *Chairman*
B. B. BAYLES

HARVEY LEROY WESTOVER

THE American Society of Agronomy records with deep regret the sudden passing of Harvey Leroy Westover. He died in Washington, D. C., on January 2, 1943, at the age of 63 years.

Today, we pause to commemorate a genial scientist, a tireless worker, a staunch friend, and a benefactor of mankind. We knew him, loved him, and revered him not only for his productive contributions to the advancement of plant science but as a sincere, and generous friend. Soft spoken and modest, yet silently zealous in his work, his extraordinary genius for unassuming leadership and lasting friendships, influenced the wellbeing of mankind here and abroad. His was a mountain of strength born of the grandeur of simplicity and an abiding faith in his work for humankind.

Because of modesty, Harvey Westover would be overwhelmingly embarrassed by the reverent tribute we pay him today. He was America's first and great creative leader in the development of the alfalfa enterprise of our country. No physical or material sacrifice was too great for him to undertake if it promised to solve the intricate problems of the expanding development of rich green alfalfa fields in regions of our nation where its potentialities escaped recognition. Plant explorations by him in Russia, Persia, Turkestan, Africa, Spain, Morocco, Argentine, Chile, and the remote regions of other countries brought to America germ plasm and varieties of alfalfa, superior in cold hardiness and disease resistance—those basic qualities for an enduring culture of America's most beneficient forage.

From the time of its organization in 1933, Harvey Westover served as Permanent Secretary of the Alfalfa Improvement Conference. In this coordination and stimulation of the efforts of American agronomists for the synthesis of superior germ plasm, he kindled and guided a renewed and productive effort. On the very day that he left his desk for the last time, he had recorded the release of the new wilt-resistant Ranger alfalfa.

Harvey Westover was born in Austerlitz, N. Y., on June 4, 1887, the son of Seymour and Anna Gott Westover. After his college work at Cornell where he received his B.S. degree in 1906, he spent five years with the Office of Soil Survey of the U. S. Dept. of Agriculture, and devoted two additional years to the classification of soils for the Forestry Division. In 1913 he joined the Forage Crops Division and began his long, persistent, and notable studies on alfalfa. In 1915 he began his long membership in the American Society of Agronomy.

Westover published many scientific papers not only in the field of his major interest but on other studies such as those of crested wheat grass, fine turfs, and lawns. He was a Fellow of the American Society of Agronomy and of the American Association for the Advancement of Science. He belonged to the Botanical Society of Washington, the American Museum of Natural History, and the Explorers' Club of New York and the Cosmos Club of Washington.

We pay tribute to Harvey Westover not only for his tangible contributions but for intangible ones, perhaps of even greater significance. He has set for us the example of the great power of simplicity, and the far-reaching beneficence of tried and true friendship.—L. F. GRABER.

WALTER HERMAN ANTHONY LEUKEL

DOCTOR WALTER HERMAN ANTHONY LEUKEL, Agronomist with the Florida Agricultural Experiment Station for the past 17 years, died suddenly April 27, 1943, at his home in Gainesville.

Doctor Leukel was born in Potter, Wis., February 17, 1886. He was educated in the public schools and the State University of Wisconsin, graduating with the B.S. degree in 1916 and received the Ph.D. degree in 1925. He served as instructor and principal of high schools in Wisconsin from 1910 to 1914. He taught in the public schools of California from 1916 to 1918 and in the public schools of Illinois from 1919 to 1922. He was in the Armed Forces of the United States during 1918–19. He joined the staff of the Florida Agricultural Station August 15, 1925.

Through his outstanding research work with the Experiment Station and through his attendance at scientific meetings, Doctor Leukel was widely known throughout the state and respected in Florida farming circles as well as the

scientific world. He attracted widespread attention in the United States and other countries several years ago by developing a special technic for observing root growth of grasses. He was the author of numerous bulletins and scientific articles.

Doctor Leukel was a member of the Catholic Church, American Legion, Phi Sigma, Sigma Xi, American Society of Plant Physiologists, and the American Association for the Advancement of Science. He had been a member of the American Society of Agronomy since 1925. For a number of years he was a member of the Committee of the Boy Scouts of America in Gainesville. He is survived by his widow and two sons of Gainesville; two brothers, John Leukel of Marshfield, Wisconsin, and Bob Leukel of Arlington, Va.; and two sisters, Mrs. Lillian Jones of Oakland, Calif., and Mrs. Charles Pritzil of Brillim, Wis.

Doctor Leukel will be remembered by his associates for his outstanding capacity for careful experimental work, devotion to ideals, and loyalty of purpose. In his death, his family, friends, and science have suffered a great loss.—F. B. SMITH.

WALTER BEAL ELLETT

WALTER BEAL ELLETT, Head of the Department of Agricultural Chemistry at the Virginia Polytechnic Institute and chemist for the Virginia Agricultural Experiment Station, died in Blacksburg, Va., May 12, 1943.

Doctor Ellett was born at Central Depot, now Radford, Va., November 11, 1874. He was graduated from Virginia Polytechnic Institute in 1894 and was immediately made an instructor in inorganic chemistry, earning his Master's degree in 1896. He went to Germany in 1900 and was graduated from the University in Goettingen in 1904, receiving the M.A. and Ph.D. degrees. While in Germany he studied under Tollens, Wallach, Nernst, Tammann, von Seelhorst, and Fleischmann. He was made chemist of the Virginia Agricultural Experiment Station in 1906. He was also made Head of the Agricultural Chemistry Department at the Virginia Polytechnic Institute in 1915, succeeding the late Professor Robert J. Davidson.

Doctor Ellett was a member of the American Chemical Society, fellow of the American Association for the Advancement of Science, Phi Kappa Phi and Phi Lambda Upsilon honorary fraternities, and had been a member of the American Society of Agronomy since 1910. His researches at the Virginia Polytechnic Institute have resulted in practical contributions to the fields of soil fertility, fixation of phosphoric acid by the soil, fermentation of fruit juices, and pasture research. His many papers have been published in the leading scientific journals and as bulletins of the Virginia Agricultural Experiment Station. In 1926, Doctor Ellett married Miss Anna Burton of Rockbridge County, Virginia, who survives. Doctor Ellett was an inspiring teacher and investigator, and above all, a thorough Christian gentleman.—H. H. HILL.

GEORGE ROBERT HYSLOP

THE American Society of Agronomy records with deep regrets the sudden passing of one of the outstanding agronomists of the West, Professor George Robert Hyslop.

Professor George R. Hyslop was born in Deshler, Ohio, November 17, 1884; academic education, Ohio State University, graduated, 1907; entered agronomic fields of education, experiment station and extension in Oregon in 1908, and at

the time of his death, July 24, 1943, was head of the Farm Crops Department and Division of Plant Industries at Oregon State College.

This simple chronicle of facts gives little indication of the kind of man he really was. It does not explain why metropolitan dailies wrote editorials mourning his loss, why innumerable farm organizations throughout the state devoted meetings to reminiscences about him, and why thousands of college graduates and students, many of them now in the Army, felt a sudden sense of desolation and personal disaster when they heard the news.

"Prof", as he was affectionately called by thousands, would have been the first to laugh heartily at any suggestion that he was a "great" man. Greatness in his mind was too tied up with ceremony and splendor. It is nearly always the simple things that determine greatness, and these things were possessed by him in a measure far beyond the reach of most of us.

He was simply and unaffectedly interested in people—people of every rank and station. The truck driver with an idea, a barefooted youngster with a whimsical viewpoint, a clerk with an interesting slant on life—all were of equal importance to him and all were of more importance than a person of note but of little personality or responsibility. He had wonderful sympathy, and people of all degrees came to him with their problems with a feeling he would understand and could help them. This quality was invaluable with students, who for more than 35 years streamed through his office, each taking away with him a warm memory of a human, understandable, humorous, and likeable "Prof". People liked him because he liked them with genuineness that no one could feign. He was tolerant of the faults of the rest of us, continually found excuses for lapses in others. Even a genuine rogue could trust in his friendship—provided he were a likeable rogue and not mean.

If one were to fish out a dominant trait, it would have to be generosity—a complete lack of selfishness. When a measure came to attention, his first thought was always, "Is this a good thing for the farmers of the state and the nation?" If the answer were "No", he was no longer interested no matter what might be the effect upon himself. He was thus often drawn into controversies that temporarily turned important people against him. His instant championship of a right measure or a friend who he thought to be in the right had no relationship to what was expedient. He had that rare trait—the ability to divorce his own welfare entirely from the issue. This was a part of his simplicity. There was no involved or tortuous argument, only the question, "Is it right?"

Nearly every professional agricultural worker in Oregon and the Pacific Northwest in general is indebted to him in some degree. He promoted and saw in actuality in conjunction with fellow workers the perfecting of grain certification and grading on a national basis, field and garden seed production development in Oregon from the class of a few hundred thousand dollar business a year to one of several million a year, championed wuth success bulb and fiber flax growing in Oregon, and was a firm advocate and believer that by the use of the right kinds of forage plants and proper management practices the dry land ranges and logged off lands could be developed to the increased benefits of livestock production.

He was on the continual lookout for new or different plants and agricultural practices and the "whys" and "wherefores" in relation to any phase of agriculture.

He was very much interested in agricultural organizations that had to do with the betterment of agriculture and was affiliated with those of importance in Oregon. His rather continuous series of press articles and other publications were

of current importance to the public and the agricultural public in particular and were generally accepted as fact and of definite value.

He would stop in the middle of a field and say, "Why is this part of the field better?" The search might lead back through several previous owners. He tried the patience of fellow teachers by his insistence upon stopping, no matter how inopportune the time, to investigate some flower in a far away field or some peculiar appearance of the grass by the roadside. But this curiosity proved to be the foundation upon which many agricultural discoveries were based, and it continually challenged the work of others and himself—seeking out the errors and demanding proof.

We pay tribute to George Robert Hyslop for his very significant tangible and intangible contributions to mankind and agriculture. To those of us who knew him, the greatest loss lies in the personality of "Prof" himself. We have lost a strong, unflinching friend upon whom to lean, and we can no longer hear his hearty laugh; or enjoy with him an odd, whimsical use of a word; or chuckle with him over some of the human reactions of the people all about.—H. A. SCHOTH.

ALFRED SMITH

ALFRED Smith, Associate Professor of Soils at the University Farm, Davis, Calif., died suddenly on August 9, 1943. He is survived by his mother; his wife, Bessie Archibald Smith; and one son, Donald, now in the Army. His son, Robert, died in the Army Air Corps a year ago.

Alfred Smith was born in Hazelton, Pa., in 1888, and received his bachelor's and master's degrees at Wittenberg College, Ohio. He was granted his doctor's degree at the University of Wisconsin in 1925. In 1914 he joined the staff of the Division of Soils (then Soil Technology) of the University of California as Instructor, and was subsequently promoted to Assistant Professor and Associate Professor.

Doctor Smith devoted much of his time and energy to teaching. He taught a general course on soils to the regular degree students and also a very popular course on soils to non-degree students. His research work was quite varied and enabled him to obtain first-hand information on numerous soil problems. These experiences helped him in teaching and advisory work. He assisted in soil survey work and carried out experiments on various phases of soil moisture relationships. Gradually he became more and more interested in the various aspects of soil temperature. He installed elaborate recording equipment and studied the march of soil temperature under various climatic and cropping conditions. His findings have been reported in numerous publications, both in scientific journals and in farm papers. Recently he contributed various sections to Gustafson's book on "Soils and Soil Management".

Soon after Pearl Harbor, when the Davis Campus was taken over by the Army, Doctor Smith again joined the Soil Survey and collaborated in surveying lands suitable for the production of guayule in the San Joaquin Valley.

Doctor Smith was a fellow of the American Society for the Advancement of Science, an honorary member of Alpha Zeta, a member of Sigma Xi, the American Society of Agronomy, the Soil Science Society of America, and the Western Society of Soil Science.—HANS JENNY.

GEORGE MATTHEW MCCLURE

George Matthew McClure, Assistant Professor of Agronomy, College of Agriculture, the Ohio State University, and Assistant Agronomist, Ohio Agricultural Experiment Station, died in Columbus, Ohio, on September 24, 1943, at the age of 54, after a long illness.

Born at Wooster, Ohio, on December 4, 1888, he attended Wooster College, and later the Ohio State University, receiving the B.A. degree in 1914 and an M.S. in 1916. From 1909 to 1912 he was chemist at the Ohio Agricultural Experiment Station, Wooster. In 1914, he was made Assistant in Agricultural Chemistry at the Ohio State University and a year later was made Instructor in Agricultural Chemistry and Soils. In 1925 he was appointed Assistant Professor of Soils. Since 1927 he has also been Assistant Agronomist, Ohio Agricultural Experiment Station.

On October 16, 1912, Professor McClure was married to Miss Orpha Mae Koontz, who survives, together with a son George, a senior in Engineering at Ohio State University and who will shortly enter the Army Air Corps, and a daughter, Mrs. Wesley Zaugg, wife of a Major in the Army Air Corps.

Professor McClure's special interest was in the field of Soil Chemistry and its application. Graduate and undergraduate students attest to the thoroughness and inspiration of his teaching and counselling. Enthusiastically devoted to the development of grassland areas, he became a national authority on the design and construction of golf courses, parks, and lawns. The Ohio State University golf course stands as a physical memorial to this devotion.

Professor McClure was a member of numerous organizations, including the University Lodge of Masons, of which he was past master, Delta Tau Delta, Alpha Gamma Rho, Phi Lambda Upsilon, the American Chemical Society, and for many years the American Society of Agronomy.—R. D. Lewis.

FREDERIC HARLAN BATEMAN

Frederic Harlan Bateman, long a member of the American Society of Agronomy and widely known for his highly important contributions to the development of improved potato-planting machinery, died peacefully at his farm home at Grenloch, N. J., October 13, 1943, at the age of 70. He is survived by Lavinia Steele Bateman, his wife, and by Frank, Frederic S., William, Ellen, and Alice (Mrs. Wallace Craig), all children by his first wife, Ellen Brace.

Mr. Bateman was born at Spring Mills (now Grenloch) on May 7, 1873. After attending Peddie Institute and graduating from Eastbourne Academy, he entered the employ of the Bateman Manufacturing Company, founded by his grandfather, Stephen Bateman, in 1836, and later directed by his father, Frank Bateman. Early in his career he took over the active management of the business and soon became president of the reorganized Fred. H. Bateman Company which continued the production of the widely known "Iron Age" line of farm machinery. Subsequently, this company was merged with the A. B. Farquhar Company of York, Pa., with which organization Mr. Bateman continued to serve in the capacity of manager of the "Iron Age" division until his death.

Being also a practical farmer, Mr. Bateman soon saw possibilities for improvement in fertilizer placement with the result that he spent a large part of his life perfecting machinery for planting potatoes, cotton, tobacco, and vegetables. Within recent years he developed a "Hi-Lo" placement by which fertilizer is

banded at the usual level on one side of the row and several inches deeper on the other, with resulting improvement in yields in many cases.

During the course of a very successful business career, Mr. Bateman was honored by the presidency of the Potato Association of America in 1937. In 1938 he was awarded a medal of honor by the Pennsylvania Cooperative Potato Growers Association, and in 1942 the gold medal of the New Jersey Agricultural Society was awarded him by the New Jersey State Potato Association. He was elected a Fellow of the American Association for the Advancement of Science in 1940, and in 1941 was elected General Chairman of the National Joint Committee on Fertilizer Application and presided at the annual meeting in St. Louis in 1942. At this time he was presented with a handsome album of letters from friends prominent in agronomy and the fertilizer industry, expressing appreciation of the high esteem in which he was held as a man and for his valued contributions to fertilizer placement and to agriculture in general. In January 1943 he was given a citation for "outstanding service to Agriculture" by the New Jersey State Board of Agriculture.

The people of his home community thought of him as the genial Superintendent of the Sunday School, in which capacity he served 25 years. For a period of 44 years he served as Elder in the Presbyterian Churches of Blackwood and Grenloch, and was also for many years a member of the Board of Trustees. With the passing of this scientist, manufacturer, farmer, and Christian gentleman, we have lost a highly esteemed associate and friend.—F. E. BEAR.

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MINUTES OF THE CROPS SECTION OF THE AMERICAN SOCIETY OF AGRONOMY

THE business meeting of the Crops Section of the Society was held on Friday morning, November 12, 1943, in Cincinnati, Ohio.

The reports of the committees on Varietal Standardization and Registration, Nomenclature of Genetic Factors in Wheat, and Methods of Seed Production and Utilization of Improved Strains of Forage Crops were read and approved. The report of the committee on Crop Terminology was presented by Dr. C. J. Willard with the request by him that it be approved provisionally, subject to amendment and formal action at the next meeting. This report was so approved. All these reports appear elsewhere in this JOURNAL as a part of the Minutes of the Thirty-sixth Annual Meeting (pages 1050 to 1055).

The Nominating Committee, consisting of Dr. H. K. Hayes, *Chairman*, Dr. O. S. Aamodt, Dr. B. A. Brown, Dr. D. W. Robertson, and Dr. R. L. Lovvorn, nominated Dr. I. J. Johnson, State College of Agriculture, Ames, Iowa, as Chairman of the Crops Section for 1944, and Dr. E. N. Fergus and Dr. G. A. Wiebe as members of the Program Committee. They were unanimously elected.—L. F. GRABER, *Chairman, Crops Section.*

NEWS ITEMS

DOCTOR WALLACE WORZELLA, formerly of the Department of Agronomy, Purdue University, has been named head of the Department of Agronomy, South Dakota State College, Brookings, S. D.

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DOCTOR HELMUT KOHNKE has been appointed Soil Scientist at the Purdue University Agricultural Experiment Station, Lafayette, Ind., with the rank of Associate Professor in the University. Doctor Kohnke has been conducting hydrologic research for the last several years with the Soil Conservation Service.

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DOCTOR WILMON NEWELL, Provost for Agriculture at the University of Florida, Gainesville, died on October 23, 1943. Doctor Newell had been Director of the Experiment Station and the Extension Service since 1920 and Dean of the College of Agriculture from 1920 to 1938 when he was made Provost for Agriculture. He was also Commissioner of the Florida State Plant Board.

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VOLUME I of an "Encyclopedia of Applied Plant Sociology" is to be published this month in a manuscript edition by the author, Morris J. Spivack, 95 West 46th Street, Bayonne, N. J.

INDEX